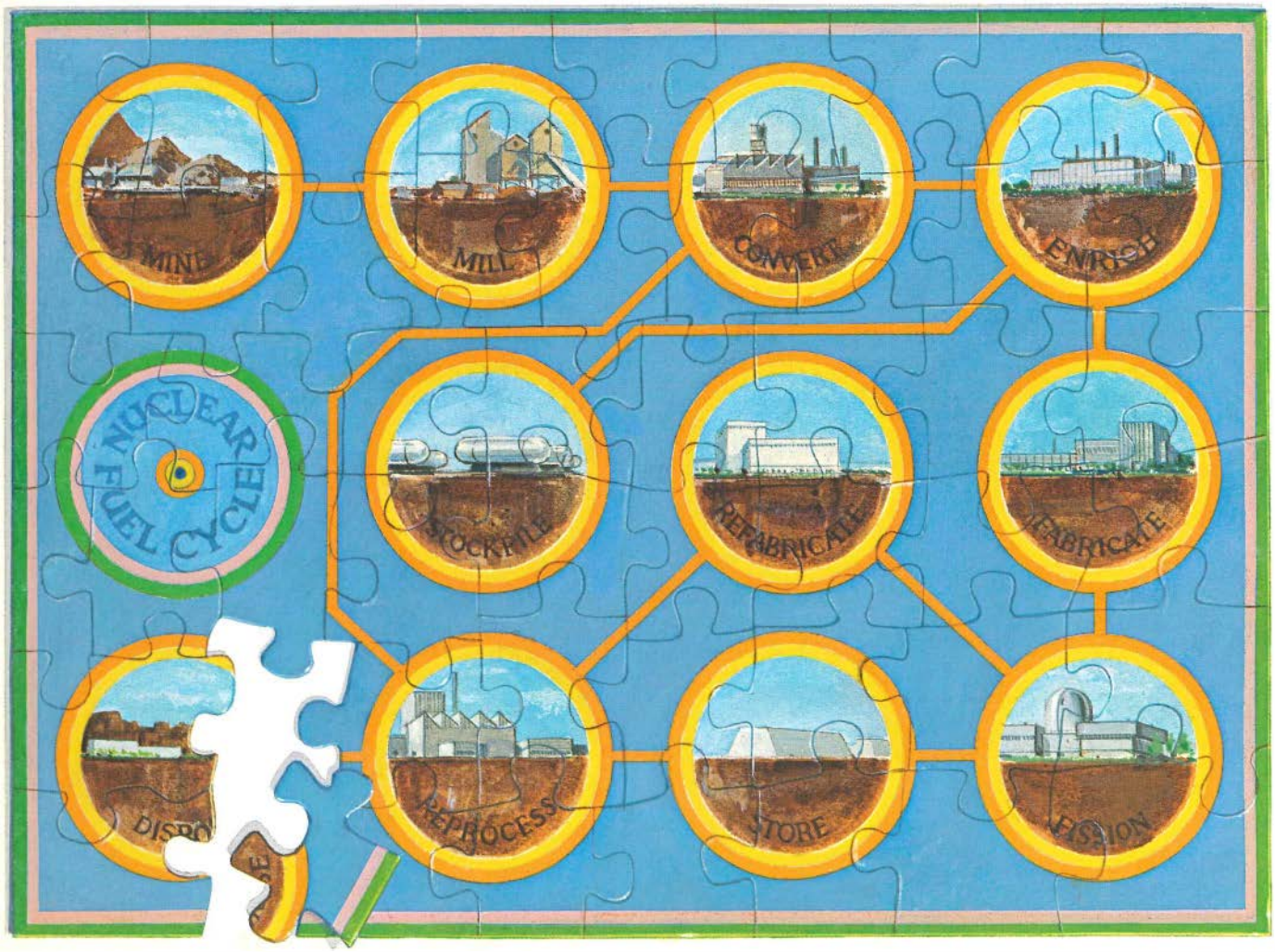
The Nuclear Fuel Cycle

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

NUMBER TWO

MARCH 1977



EPRI JOURNAL is published by the
Electric Power Research Institute.

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

EPRI JOURNAL Staff and Contributors:
Agnes Waters, Managing Editor
Ralph Whitaker, Feature Editor
Pauline Burnett, Jenny Hopkinson, John
Kenton, Jim Norris, Gordon Sheridan,
Barry Sulpor, Stan Terra, Susan Yessne.

Graphics Consultant: Frank Rodriquez

Robert A. Sandberg, Director
Ray Schuster, Assistant Director
Communications Division

Address correspondence to:
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
3412 Hillview Avenue
Palo Alto, California 94303

Cover: All the elements of the nuclear fuel cycle have been demonstrated. But three—spent fuel reprocessing, refabrication of recycled fuel, and disposal of radioactive waste—have not yet been put into commercial operation.

EPRI JOURNAL

Volume 2, Number 2 March 1977

Public Issues of Fuel Reprocessing and Waste Disposal

Standard reprocessing plants that separate uranium, plutonium, and fission products have been in operation over 30 years and in at least seven countries. With this historical experience it is strange that the worldwide reprocessing situation seems to have followed an inverted course compared with the penetration of nuclear power in the world energy supply. There are several reasons for this stalemate in the back end of the fuel cycle, including economic and financial questions raised by the instability of the regulatory issues and questions raised by the public. Within the last year, however, when 20% of the U.S. public was given an opportunity to vote on antinuclear propositions, it defeated such propositions in every case, with an average vote in excess of 2 to 1. But what of the concerns expressed by the public?

The current concerns appear to focus on hazards from two sources, people and nature—people in the form of terrorists, national zealots, and those countries or governments that cannot be trusted (including our own), and nature in the form of new ice ages, earthquakes, new volcanoes, or instability in the currently accepted laws of chemistry and physics.

These concerns are the result of an evolutionary process that started with worries over routine releases to the environment: What might small amounts of krypton 85 do to the world? Today that question is swamped by concerns about CO_2, SO_2, and NO_x.

The question of economics has been raised—industry wouldn't be able to afford reprocessing, it was said. If oil were $2 a barrel and coal $4 a ton, and if this country not only owned the oil and the coal but the coal were free of sulfur, nitrogen, and heavy metals, that criticism might be valid.

The next public issues to evolve were the ones about morality. Today there appear to be two main nuclear morality issues: plutonium and/or radioactive waste disposal and international proliferation. An EPRI report (EA-43-SR) setting in perspective the effects of plutonium is such that no further comment is required here. However, for those of you who are skilled practitioners of the art of accident analysis and environmental assessment, I suggest you do a case on your local hardware store or gas station or even on a block of old houses in your city. Take the few tons of lead, cadmium, nickel, chrome, and so on, volatilize them by burning the rubber tires, gasoline, oil, and wood, transport it all downwind—one allowable dose per person on the average—and, oh yes, don't forget to make nickel carbonyl out of the nickel and carbon monoxide out of 10% of the tire carbon and 1% of the wood carbon. Don't exaggerate anything—just do the calculation the way you now do nuclear calculations and extend it nationwide, then worldwide—and with the large number of gas stations,

---

This subject was discussed by Mr. Levenson at the November 1976 meeting of the American Nuclear Society.

hardware stores, and houses, the calculation marks the end of civilization. Of course, it's ridiculous. It does not mean that no one will ever die from such causes, but catastrophe is something else.

The statement that radioactive wastes will remain radioactive for hundreds of thousands of years is, of course, true. Almost everything in the world is naturally radioactive. The fact is that several independent calculations show that the radioactivity of the wastes decays to a level less than that of the uranium used to produce them in time periods of hundreds of years, so the operation of nuclear reactors will result in *reducing* the total radioactivity of Earth's crust.

But what about international proliferation? Like some of the other concerns this one also seems to have evolved—in this case from a failure of diplomats to develop international agreements on disarmament and nonproliferation. But whether a U.S. moratorium on reprocessing would deter any other country from proceeding is highly questionable—in fact, because of economic pressures, a moratorium would probably force expanding nuclear power countries into providing their own reprocessing. One suggested alternative solution to this problem includes the development of a so-called tandem fuel cycle, requiring that large numbers of heavy water reactors be built in addition to light water reactors. This is somewhat puzzling in the context of disarmament when we realize that not only did India choose to make its weapon plutonium from such a reactor but when the U.S. government chose its second generation of reactors to produce weapons material, the choice was heavy water reactors—perhaps the most flexible weapons factory there is!

Civil liberty is another issue of extreme importance, but since I have to conclude that the guarding of thousands of nuclear weapons—in production, in transit, and in deployment—combined with air travel passenger screening and occasional search, have not appeared to impact personal liberties in any significant way, I personally find it hard to believe that reasonable nuclear safeguards will do so. The general concern about terrorists is very real, but plutonium or radioactive wastes certainly do not add a new dimension to the problem. There have been 1000 ways to threaten a modern city and we may now have 1001.

Whether fact, opinion, or fiction, these all remain issues with some part of the public, albeit a minor part. Stories of grizzly bears in national parks can bring terror to the hearts of people who will never go there even though the injury rate is only one per two million park visitors, and the death rate is much lower. Yet these people build homes on a flood plain and reject any thought of hazards from floods almost guaranteed to occur. If a terrorist were to obtain some plutonium, load small quantities of it into hundreds of aerosol cans of hair spray, he could probably generate a public health hazard approaching that of the cigarette industry—yet there is no question as to what the difference in public reaction would be. In a recent paper P. Slovic

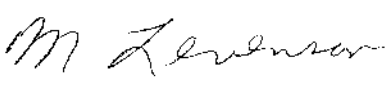
reported that a risk benefit survey indicated many people believe the automobile and the nuclear power industry represent the same risk to human life—one kills 50,000 people per year in the U.S. alone and the other has not killed one person in all the years of its existence.

But let us return to what appear to be the primary public concerns today. Is it more appropriate to leave future generations with both risks and benefits or with neither risks nor benefits? If the latter were possible, it might be the solution, but it cannot be achieved. A moratorium on nuclear power will clearly lead to diminished fossil reserves for future generations. Such a risk, since it cannot be reversed, might well be a risk we should not be willing to leave as our heritage. Properly handled and stored wastes represent a declining hazard and one that can be corrected if an error is made.

The international proliferation issue is quite different—the barn doors never were there. Any country that so desires probably has the resources available to build at least a small nuclear arsenal. The U.S. did it with relatively low-technology, graphite–natural uranium reactors and with separation processes that would be relatively primitive in today's world. None of the countries that detonated plutonium bombs used power reactor plutonium as the explosive.

If there is any message at all in this very real concern it would appear to be that instead of a moratorium, the responsible nations of the world should be taking a leadership role in providing a service to others so that they are not forced to develop their own capability. Only an aggressive program will succeed in developing technical deterrents as contrasted to prohibition. Our society really accepts as regulations or restrictions only those things that aren't too inconvenient and where the regulators' choice is one from among a group of acceptable alternatives. As a nation, the U.S. honored neither the prohibition of alcohol nor the mandate on seat belt interlocks.

We can only conclude that very little is really understood about the concerns of the public at large, except that perceptions carry more weight than facts and perhaps therein lies our challenge. While the temptation to argue back may be great, our real goal must be honest, objective assessment and, perhaps most important, the recognition of which alternatives really exist and which alternatives and energy sources are still only hopes.



Milton Levenson, Director
Nuclear Power Division

When the JOURNAL began, we knew its format and style of presentation would always be unfinished business. Now that a year has passed, we know two more things: we're too technical, and we're too general!

Actually, we have two types of reader. One is interested—and perhaps influential—in energy affairs generally or in utility management specifically; but this reader isn't an R&D pro. The other is closely involved with a specific technology, perhaps even contributing to its development.

Understandably, these readers don't have the same needs. In fact, they don't even read the same language. So, beginning this month we give the front of the magazine to the generalist, with state-of-the-art features; interviews; descriptive summaries of EPRI research findings; our column of news, At the Institute; and Project Highlights from our R&D sponsorship.

The rest of the JOURNAL contains technically focused material, principally the R&D Status Reports from each technical division, but also technical features and abstracts of New Technical Reports from EPRI.

Incidentally, no one needs special permission to read the entire magazine —just time. And anyone, even if he or she reads no more than this page, may send along suggestions or comments on how the JOURNAL can be more useful.

□ Closing the nuclear fuel cycle has been a long, hard job, now on the verge of completion—or is it? Industry professionals have made all the qualifying moves, but even though the technology has fallen into place pretty much as foreseen, they aren't having that luxurious feeling of success.

What impediments stand in the way? Which are institutional and which are technical? How do they relate to each other? And what are the implications of the passage of time without resolution?

John Kenton, EPRI's communications specialist for nuclear power, has answers based on 23 years spent in reporting and interpreting nuclear industry developments for New York papers, McGraw-Hill, and Atomic Industrial Forum publications. Checked and updated with EPRI technical managers, those answers are the basis of Kenton's article, "Completing the Nuclear Fuel Cycle" (page 6).

□ This month's technical feature treats another matter of unfinished business. In this case, the way to resolve it seems to be what everyone's math teacher used to say: Go back and check your work, including your theory.

Gerald Lellouche does just that in "ATWS—Impact of a Nonproblem" (page 37). He deals pointedly and interestingly with a tough hypothetical problem in the only way possible—theoretically. Theory in nuclear power matters isn't new to Lellouche. It's been his professional life for 25 years, much of that time with Brookhaven National Laboratory, where he was a staff physicist in theoretical reactor physics and a member of the AEC Department of Reactor Licensing Technical Assistance Group.

Since June 1974 Lellouche has been a program manager in the Safety and Analysis Department of EPRI's Nuclear Power Division. He has a BS degree in chemical engineering from Purdue University and a PhD in nuclear engineering from North Carolina State College.

□ There is still other unfinished business among energy affairs. Washington economist Bruce Netschert touched on one example when interviewed about the perceptions he brings to the EPRI Advisory Council, of which he is vice chairman. If we are to do anything constructive about an energy problem, Netschert told the JOURNAL's Stan Terra, we first must agree that the problem really exists. All progress depends on public understanding, he feels. That's why "Bruce Netschert Calls For Energy Problem Alert" (page 12).

□ One approach to unfinished energy business is to identify and assess the task. Sometimes there is one agreed priority and only its dimensions are unclear. More often, there are several ways to go—all with different functional and economic benefits. The utility planner's handy tool in such cases is his system model.

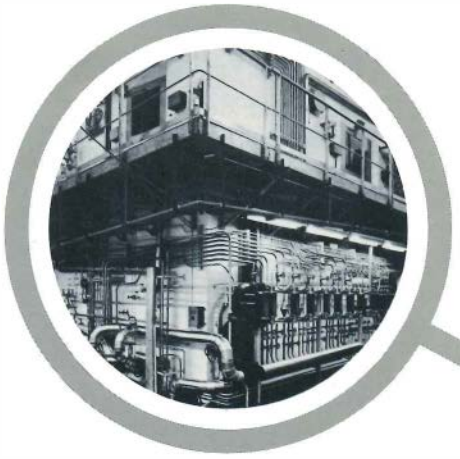
EPRI now has six system models available to help determine which research avenues may be most productive. The utility systems are all hypothetical, and because they have been idealized for broad applicability, the resulting programs are interchangeably called model systems or system models. We chose the latter: "Utility System Models" (page 16).

Lellouche

Completing the Nuclear Fuel Cycle

Few unresolved technical issues block recovery of the vast energy potential in the reusable nuclear fuel remaining after the material's first pass through the reactor. ▫ An EPRI state-of-the-art feature

Twenty years have passed since the Atomic Energy Commission, having been unsuccessful in its efforts to encourage private industry to enter the field of reprocessing spent nuclear fuel elements, took a specific step in that direction. As an inducement for the construction of a privately financed reprocessing plant, it offered to share the fuel reprocessing then done in AEC plants. At that time, April 1957, Shippingport was the only commercial-type power reactor in operation, Yankee-Rowe and Dresden 1 were under construction, and there was not enough commercial reprocessing to keep a private plant busy. The AEC move led to the formation of the Industrial Reprocessing Group, a pool including five utilities, that eventually



built the world's first privately financed nuclear fuel reprocessing plant—the plant near Ashford, New York, known today as the West Valley plant.

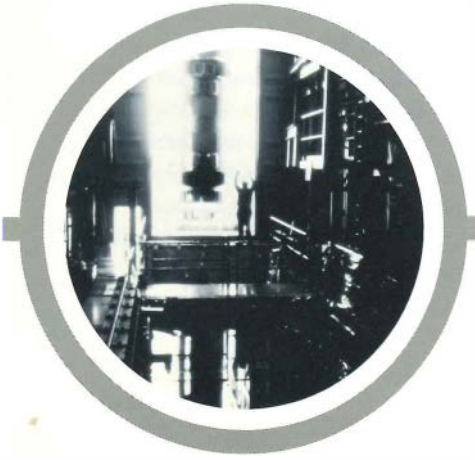
All this is history. But it helps throw a little perspective on how long the U.S. has been trying to close the back end of the fuel cycle. Since then, the rosy-futured civilian atom has been politicized and has become a storm center of controversy. Ironically, this came about after nuclear power generating cost had been brought down to levels below those of fossil fuels by margins undreamed of 20 years ago, and after nuclear power had compiled the best safety record of any industry.

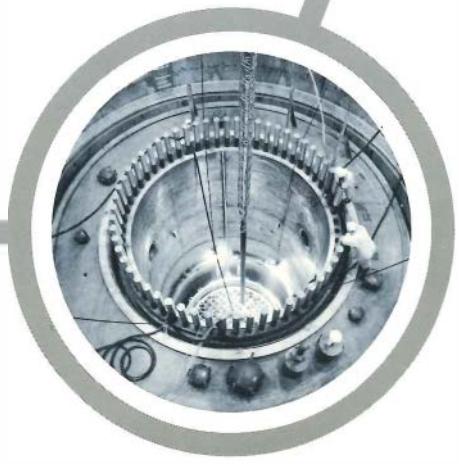
Yet in the last few years the goal of closing the fuel cycle has seemed to recede with each passing year. To a large extent this may be attributed to causes rooted in the need to adapt our institutions so they can effectively regulate a new technology and in the rejection of nuclear power by a small but vociferous minority in spite of 2–1 majorities favoring nuclear power in seven state initiatives last year.

Aside from nationwide public acceptance and the regulatory and political issues, what are the technical issues requiring resolution before the back end of the fuel cycle can be closed?

What is the fuel cycle?

When fossil fuels—coal, oil, natural gas—are burned, no fuel remains. The residue of the combustion process goes up the stack as gaseous effluent, and in the case of coal, there is also solid





residue in the form of ash or slag. By contrast, when uranium is used as fuel for power generation, not all the uranium loaded into the reactor is consumed by fission before the reactor needs to be recharged. The unconsumed uranium can be recovered and refabricated to go back into the reactor. Similarly, fissile plutonium, produced in the reactor by transmutation from ordinarily non-fissile uranium-238, can be separated, fabricated into fuel, and loaded back into the reactor.

For this reason the term *nuclear fuel cycle* has been used to describe the life history of a given amount of uranium from its mining through its milling, concentration, purification, enrichment, and fabrication into fuel; its residence time in a reactor, during which a part is fissioned to produce heat energy that is converted to electricity (leaving behind fission products or nuclear waste); its reprocessing and the separation of the useful fissile material from the waste, and the refabrication of the latter for return to the reactor. There are a number of alternative fuel cycles, based on various possible ways of using fissile uranium, plutonium, and thorium.

Just what is required to close the fuel cycle? Essentially, three things: (1) to establish cost-effective reprocessing services able to meet the demand; (2) to establish recycling, fabrication, and commercial use of plutonium fuel, with acceptable safeguards against diversion to illicit purposes; and (3) to establish a system for management of radioactive wastes that is acceptable to the public—whether by permanent disposal or, initially, by retrievable storage. It has been generally accepted that the third item is the responsibility of the federal government and the first two, those of the private sector—under federal regulation, of course.

The technical issues

The strictly technical issues that remain to be resolved before the fuel cycle can be closed are few, if any, and most arise only if certain political or administrative restrictions are imposed on the contemplated system.

Mainly, what remains to be done is large-scale demonstration. Reprocessing has been demonstrated on a small scale at West Valley over its six years of successful operation and in over 180 plant years of large-scale government operation and in commercial practice. However, the West Valley plant was closed because it was too small for economical operation after other commercial reactors had come into service. Waste disposal, on the other hand, has been demonstrated in the laboratory, but only piecemeal (and at pilot scale in an integrated fashion in France). A full-scale demonstration is needed to show the nation that the technology in hand can be safely scaled up to planned industrial sizes.

Recycling

The government and the nation must decide how long the recycling in LWRs of fissile material from spent reactor fuel can be delayed. The question really is *when* rather than *whether* we begin recycling for the rather fundamental reason that by the year 2000 the energy content of U.S. spent power reactor fuel—assuming a moderate nuclear power growth to 500 GW by 2000—will be the equivalent of 19,125 million barrels of oil, worth more than $300 billion at an oil price of $16/bbl. Added to this immediate fuel value are the effects on the national balance of payments by the offsetting of oil imports and the stabilizing influence on the price of virgin uranium by the availability of recycled fuel.

Other measures of the energy potential in fuel-cycle by-product material are equally dramatic.

- If used as fuel in breeder reactors, the depleted uranium already on hand from past enrichment operations contains more energy than do all our coal reserves; assuming an average coal price of $50/ton over the next 24 years, the depleted uranium is worth $50 trillion in equivalent energy content.
- Recycling uranium and plutonium in LWRs alone would give the U.S. the equivalent of three years of extra electricity (extra in the sense that it would be without other energy-source input), according to EPRI calculations.
- Total energy content of the whole free world's spent fuel will be about 97 billion barrels of oil by the year 2000, equal to six times the free world's production of oil in 1975.
- The fissile material recovered from the spent fuel of four LWRs is sufficient to fuel a fifth.

In the light of all this, it does not seem reasonable to consider prohibiting the use of an energy resource of such magnitude in an energy-needy country.

An ERDA study just published *(Benefit Analysis of Reprocessing and Recycling Light Water Reactor Fuel)* shows that the so-called throwaway fuel cycle in which spent fuel is not reprocessed is not less but more expensive than recycling, largely because 25% more uranium must be mined and enriched to fuel the same number of reactors. ERDA estimates the throwaway cycle will cost $27.5 billion more between 1976 and 2000 in total fuel cycle cost than if six 3000-tU/yr separation plants and mixed-oxide fuel fabrication plants were brought on the line by 2000. The ERDA study goes on to show that over the lifetime of those plants, the total benefit from recycling, when compared with throwaway, mounts to $76.7 billion. For the individual consumer, the difference in using recycling is 0.7 mills/kWh cheaper power.

With throwaway, the spent fuel must still be packaged and put underground for disposal, so nothing is gained in that regard—and there is the added drawback that about 16 times greater space is required to store unreprocessed spent fuel than processed waste.

Another frequently cited concern is nuclear proliferation. Some argue that the proliferation risk outweighs the potential economic and resource-conservation benefits of nuclear energy. This argument fails to recognize the technological realities of nuclear power: the necessary technologies are well known, proven over 30 years, and already disseminated worldwide. Foregoing the benefits of peaceful nuclear energy, at most, can be but a minor impediment to the development of nuclear weapons in any of 30 or 40 nations of the world. All elements of nuclear technology are so well in hand that control of the spread of nuclear weapons must rely on statesmanship and political action, not on technology embargoes.

Finally, it may be noted that nearly all projections of nuclear power growth indicate that by the year 2000 the U.S. will no longer have 50% or more of the world's power reactors but will have slipped to about 33% in 1985 and 25% in 2000. World inventory of spent fuel is expected to increase by a factor of 100 by the end of this century. Other countries are either building or contemplating building reprocessing plants to augment their nuclear fuel supplies.

If, then, it may be assumed for the purpose of this article that it is only a matter of time until recycling of nuclear fuel in LWRs begins, a few technical questions present themselves.

Technical consequences of delay

The longer the spent fuel is allowed to cool, the more readily it can be handled because of radioactive decay. Therefore, paradoxically, the longer recycling is delayed, the relatively easier it becomes to illicitly reprocess the fuel and to that extent, the more difficult the safeguards problem.

In addition, if recycling is long delayed for political reasons, some assumptions about nuclear fuel management would require review—assumptions that have been taken as axiomatic by the developers of civilian nuclear power, both government and industry, since the beginning of nuclear power development in the mid-1950s.

- Initial fuel enrichment would need review.

- The packaging and storage of spent fuel assemblies over longer periods of time than contemplated is another area that would require study.

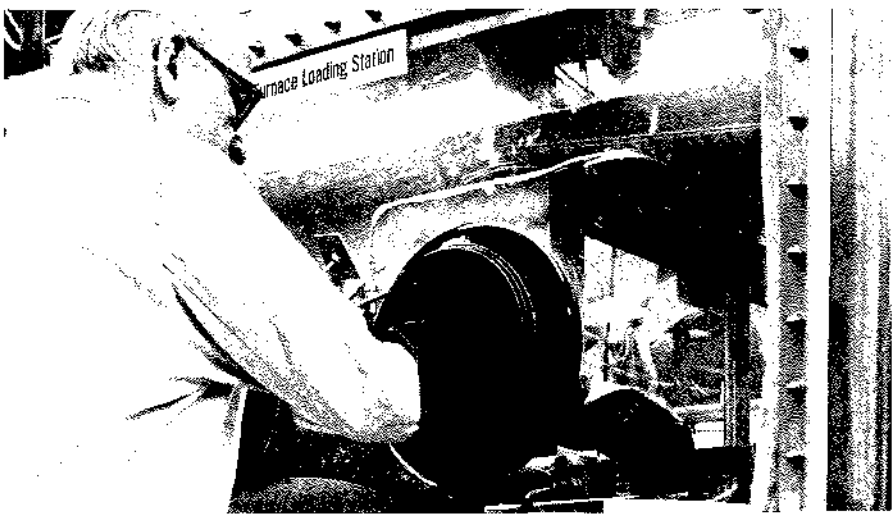
- A technical question might arise on whether the tendency of Zircaloy to corrode over longer periods would eventually affect its ability to retain fission products in the stored fuel.

Fabrication of fuel elements of so-called mixed oxide—a mixture of uranium dioxide and plutonium dioxide recovered from spent fuel during reprocessing—poses no outstanding technical problems. There is considerable experience, both in the U.S. and abroad, in the fabrication of mixed oxide: the technology is straightforward, well known, and well understood. Some 2500 mixed-oxide rods have been irradiated in five commercial U.S. reactors since 1966. Production capacity in the U.S., Canada, Western Europe, and India is estimated to be 125 t/yr and cumulative production through 1976, about 65 t/yr.

There is one qualification that might be mentioned. If the maximum occupational radiation dose per quarter, which has been sharply reduced several times in the last two decades, were to be reduced still further, or if the exposure of recycled plutonium increases—as it will if recycling is implemented—it might become necessary to automate further the present fabrication processes. These have been carried out in glove boxes that are quite adequate to shield the worker from the alpha-ray emission of plutonium. (Alpha rays, as is becoming fairly widely known, can be blocked by a sheet of paper.) But remote maintenance is a mechanical engineering, not a scientific, problem; it has been carried on with notable success at the AEC–ERDA reprocessing plants at Hanford and Savannah River for three decades.

Reprocessing

As with recycling, the technology is straightforward and well understood. The only problem other than those of



All or virtually all the plutonium power reactor fuel that has been fabricated to date was made in glove boxes like this one. The heavy rubber gloves and thick Lucite windows are more than enough to stop the low-energy alpha rays emitted by plutonium. The boxes are airtight and under negative pressure so that any leak results in inward flow; further, the boxes are constantly ventilated, with the vented air filtered and held in tanks for a specified period of time prior to release.

a political or regulatory nature is one best described as a problem of technology transfer. How can the successful operation of the Hanford and Savannah River plants be transferred to commercial practice?

Tooling up by equipment manufacturers to supply the specialized components needed is the heart of the problem. For example, Nuclear Fuel Services, Inc., (successor to the Industrial Reprocessing Group) gave up its plans last September to expand and modernize its West Valley plant, citing ever-changing regulatory requirements for obtaining a construction permit; the cost of the planned expansion had risen from $15 million in 1972 (when the plant was shut down) to $600 million, and the time estimate for carrying out the work, from 2 to 16 years.

Allied General Nuclear Services has a similar tale to tell about changing federal requirements, which have stalled startup of its Barnwell reprocessing plant since its completion a year ago.

Behind these delays and sharing in their cause is the fact that the basic components of a chemical reprocessing plant for spent nuclear fuel are not commercially available. Until now, everything has had to be custom-fabricated by the architect-engineer and its subcontractors. General Electric's problem at its Morris, Illinois, reprocessing plant arises from the fact that equipment for continuous operation at commercial scale would not work as designed for a promising new process that was a departure from the standard, proven Purex process developed by the AEC.

If for the sake of argument one accepts the assumption mentioned earlier that it is only a matter of time until reprocessing and recycling begin, then the demand for basic reprocessing plant components will have to be met. According to a recent study by an industry review group of the Atomic Industrial Forum, a U.S. capability of 9 or 10 reprocessing plants having an average annual capacity of 1500–2000 metric tons each will be needed by 2000. These plants will entail a capital investment of some $15 billion (1976 dollars), including the associated systems: shipping casks and trucks or railroad flat cars, spent-fuel storage facilities and interim on-site waste storage, treatment and packaging facilities. Thus, once the government has given a green light to reprocessing by U.S. industry, the market will be there for component manufacturers.

Another benefit from commercialization of reprocessing equipment, in the economic as well as the safety area, is the added margin of reliability to be obtained from standardization of parts and designs.

Safeguards

The question of diversion of plutonium to illicit ends, whether by foreign adventurers or domestic terrorists, has given rise to more serious concern (both real and fancied) than almost anything else in the nuclear field.

The reason why the reply has not been given too high a profile is obvious: one doesn't post details about the lock on the barn door where the horse-thieves can read them. But in fact, reprocessing plants can be equipped with adequate safeguards, using existing technology.

There are computer systems in use that provide control by tracking every discrete container and fuel rod containing plutonium as each moves from station to station and room to room within a fabrication or assembly plant. Similar systems applicable to the control of plutonium compounds in liquid or powder form are under development.

Also, at least one U.S. reprocessing plant is equipped with concealed scales in the floors of corridors that register in a central control room the weight of anyone passing over them, making it possible to detect whether anyone is coming out heavier than he went in—that is, with heavy substances concealed on his person. Hidden, closed-circuit TV cameras and concealed mirror systems that "see" around corners are also in place in at least one plant.

Detection instrumentation available today makes it possible to discern 0.25 g of plutonium within a volume of several cubic feet of radioactive materials, such as waste.

Another approach to safeguards is the so-called denatured fuel cycle, recalling the Roaring Twenties and the denaturing of alcohol during Prohibition to foil its diversion for beverages. In the denatured nuclear fuel cycle, ruthenium-106 and zirconium-95, and perhaps some cesium and cerium isotopes in the fission products, could be retained with the plutonium separated from spent fuel and not separated out with the waste stream. Or other radioactive isotopes could be mixed with the plutonium that would make it much more hazardous for the thief or hijacker to make off with the substance and much more difficult to fashion a bomb. The selection of denaturant and its amount could be based on either incapacitating the thief or rendering the material unsuitable for explosive use because it would fission prior to detonation, resulting in a "fizzle." The additives would not affect the use of the material as power reactor fuel, but the volumes required might pose a problem. The strategy depends on the adversary one is denaturing against and involves some technical questions as yet not entirely resolved. Against a small band of terrorists, simple forms of denaturing would be effective; but against a country possessing sophisticated technology, denaturing would not be entirely foolproof.

It has been pointed out, however, that such stratagems become trivial in the light of the tens of thousands of plutonium-containing weapons dispersed around the world, plus components in weapons-fabrication plants.

Perhaps the fact that there has never been a successful terrorist diversion from such plants over the 30-odd years of their existence is worthy of consideration.

As for *what if?* scenarios of sabotage to a reprocessing plant: the defenses against sabotage are largely an engineering problem. The question is how much, if anything, needs to be added to the already formidable defenses against radioactivity measured in feet of concrete and inches of lead that shield fuel materials. Hence, there are no serious technical issues outstanding.

Transportation

Once more, it can be said that there are no technical transportation issues that preclude the closing of the fuel cycle. Spent fuel has been shipped around the country without accident in increasing volumes since the first nuclear submarine, the *Nautilus,* was refueled for the first time in April 1957. Since then, the Navy's operating nuclear fleet has grown to 106 submarines and 8 surface ships at sea, most of which have been refueled at least once on the East or West Coast and the spent fuel shipped inland to one of the federal reprocessing plants. There are now 66 operating commercial nuclear power plants, most of which have been refueled once or several times. In some cases the spent fuel is stored at the reactor site, awaiting operable reprocessing plants; in others the fuel was shipped to a plant in operation or expected to begin operation shortly.

While in operation from 1966 to 1972, the West Valley plant reprocessed some 24 batches of power reactor fuel. As of mid-1976, there were 16 shipping casks operable in the U.S., each with a capacity of from 1 to 18 fuel assemblies; 4 more were under construction, and 12 more on order. Such shielded casks have been criss-crossing the country by rail or truck trailer for more than 25 years. ERDA estimates 4000 shipments of spent reactor fuel over that period logged a total of some 10 million miles without a single accident involving radiological injury. Perhaps the proof of the pudding is that there have been about half a dozen vehicular accidents, yet no release of radioactivity. Recently, a truck carrying a spent-fuel cask overturned; the accident was serious enough that the driver was killed, yet scratched paint was the only damage to the cask.

There should be little hesitation in accepting the proposition that the transportation needs of the nuclear fuel cycle pose less hazard to society than the transportation needs of any other source of energy in use today.

Such unresolved transportation issues as do exist are all in the administrative and regulatory domain: statutes by some local jurisdictions that restrict the movement of radioactive materials, lack of conformity among the states in regulations governing weight of shipment and hours of movement, proposed restrictive regulations by railroads, and the like.

An unresolved regulatory question is a judgment on the principle of colocation, which means that plutonium fuel fabrication plants must be located on the same site as reprocessing plants to eliminate the shipment of plutonium over any distance from reprocessing plant to refabrication plant. An argument against this proposal is that it is similar to robbing Peter to pay Paul because it lengthens the distance the refabricated fuel must travel to the reactors. Colocation involves economic and risk probability analysis questions, but no technical problems.

Waste management

A comprehensive study on this subject by EPRI *(Status of Commercial Nuclear High-Level Waste Disposal)* was summarized in the July-August 1976 JOURNAL. The study concluded that there are no unresolvable technical issues; that, in fact, each stage of the waste-handling process has been successfully demonstrated—and by at least one if not several methods—at laboratory scale or pilot-plant scale; and that what remains to be accomplished is merely demonstration of the integrated process at industrial scale.

A question regarding the economics of nuclear waste management that has long been put forward is whether it might become possible to solve or alleviate the waste disposal problem by finding safe, profitable uses for the material now seen as waste. Oak Ridge National Laboratory, among others, has been studying this for many years. Until now, cost has been the bar that has made this seem almost inconceivable. Recent reports point out, however, that at today's prices for rhodium ($225/troy oz), ruthenium ($60), and palladium ($40), there is clear incentive to recover these metals, which are among the elements formed when uranium is fissioned. Essential because of their catalytic properties, electric conductivity, and resistance to chemical corrosion, heat, and oxidation, these metals' market value is heightened by their scarcity. The U.S. produces less than 2% of its requirement for these metals, which in 1974 was 1.9 million troy ounces. Yet by 1990, spent fuel discharged each year will contain between 850,000 and 1.3 million troy ounces. Recovery of these and possibly other strategic metals from reactor waste is technically and economically still over the horizon today, but should be borne in mind.

To conclude: the technology is in place today to get the maximum energy from nuclear fuel by recycling it (at least in LWRs, if not also in breeders—but that is another question). There are no significant technical problems blocking the mainstream of a closed fuel cycle, only the peripheral ones that have been mentioned that might arise in the course of scale-up or in the wake of administrative-political restrictions.

Bruce Netschert Calls for Energy Problem Alert

A respected Washington economist, vice chairman of EPRI's Advisory Council, urges government and industry to convince the public that we have a serious energy problem.

▫ An EPRI interview

Bruce Netschert, a consulting economist for National Economic Research Associates with more than 25 years' experience in and out of government who views problems from the vantage point of Washington, D. C., believes that "one of the most crucial issues facing the country today is the need to convince the American public that we indeed have a serious energy problem that is bound to get worse with time."

From what he reads and observes, says Netschert, it is evident the public believes that the oil shortage following the Middle East embargo was created by oil companies to justify raising their prices and that government attempts to deal with the shortage merely reinforced a false issue. This public disbelief "is going to hamper all efforts by both industry and government to deal effectively with the problem," Netschert adds.

Netschert feels that primary responsibility for impressing the public with the seriousness of the energy problem rests with the government, at all levels, and that the White House should take the lead and set the tone. Netschert notes that the Ford Administration never made energy an "overriding policy issue," and he's taking a "wait and see" stance toward the new Carter Administration. Since energy is pervasive in our economy, says Netschert, agencies at all levels—from the policy-setting Federal Energy Administration to the local city council—must share responsibility in setting the pattern for coping with the energy issue. He sees the necessity for the federal government to give "the highest national priority" to solving the energy problem. "It deserves every kind of emphasis the government can give it," he stresses.

Since Congress tends to reflect the mood of the country, Netschert observes, it is not surprising that Congress has not taken the lead in addressing the energy problem when its constituents are largely unaware of the issue. So Netschert feels that criticism of Congress for not pushing energy solutions is unjustified, given political realities.

Netschert points out that industry act-

"EPRI should never become a spokesman for the utility industry—that would destroy its credibility."

ing alone cannot be as effective as government because of the public's tendency to view such efforts by industry as self-serving. Industry and government together, he believes, ought to launch "a massive information campaign" with the message that if we don't prepare to meet our energy needs, the consequences "could bring economic growth to a halt, interrupt the whole productive mechanism of this country, and throw us into a depression."

Netschert, who is vice chairman of EPRI's Advisory Council, notes that the Council's Committee on Communications has recommended that EPRI assume the role of an information "broker," serving as a source of technical information on the utility industry for the public press, for instance. EPRI would thereby help to get the energy message to the public, in addition to its primary mission of providing research and development for the utility industry. However, Netschert reflects the Council's feeling that in taking on this information role, EPRI should maintain the objectivity on which its public acceptance rests and should not become an advocate in controversial issues. He cautions that "EPRI should never become a spokesman for the utility industry—that would destroy its credibility." Netschert adds that EPRI's communications program thus far "has done very well" in maintaining objectivity.

An important benefit that Netschert foresees coming from a deeper public understanding of the dimensions of the energy problem is "a more balanced appraisal by the public of the conflict between energy production and environmental protection." Up to now, whenever a policy conflict has arisen between energy and the environment, he notes, "the environmental forces have usually won, hands down."

Netschert says there is a need to make clear to the public and the appropriate regulatory agencies that "it may not be possible to satisfy completely both our energy needs and our environmental goals." He cites the case of the environmental goal of zero discharge of waste heat into the adjacent waters. "What this means, in effect," says Netschert, "is that it doesn't matter what zero discharge does to our capacity to provide energy, we're just not going to allow discharge into the water. I think this position is unbalanced."

"It may not be possible to satisfy completely both our energy needs and our environmental goals."

Since the "cumulative, long-term effects of the energy-environment trade-offs now being made are not yet evident, the public is not aware of the implications of these trade-offs," Netschert tells us. He cites the possibility of a shortage in electricity generating capacity in the 1980s as one result that may occur. Although new technologies are being developed to meet energy needs and environmental concerns, Netschert notes, it will take several decades for many of these technologies to have any significant impact. "There is no easy solution, no matter how good we are in our technology," he says.

Netschert would like to see the electric utilities, which supply nearly 30% of the primary energy consumed in the country, develop "imaginative ways" of encouraging consumers to use less electricity. He points to the example of a few utilities in the East and Midwest that finance the placement or upgrading of insulation in customers' homes and allow them to repay by installments on their monthly bill.

"The electric utility industry has got to start thinking imaginatively about the *use* side of electricity," says Netschert, "as well as the supply side, where utilities have been quite effective in improving technology and getting better efficiency." Efforts to reduce demand will benefit the utilities, he notes, during this period of spiraling inflation that is driving up the cost of new plants and equipment. "By reducing their enormous investment needs, utilities will benefit themselves and their stockholders, given the burdens that new financing now places on them," says economist Netschert.

Netschert has visited more than 150 industrial and commercial plants around the country to get a firsthand look at the nature, characteristics, and flexibility of industrial energy use. He found that most plants have energy conservation pro-

grams that achieve varying degrees of overall energy savings, averaging between 15% and 20%. Most of the programs were begun as a response to the high cost and uncertain supply of fuel following the Middle East oil embargo rather than from prompting by federal energy conservation policies.

Significantly, Netschert found that "the opportunities for conservation by industrial users of *electricity* are quite limited because of the nature of its use." In many cases, most of the electric power goes into a plant's basic process, for example, driving motors that run the machinery or powering the electroprocess in making aluminum. When the power is used mainly for a plant's lighting, heating, ventilating, and air conditioning, however, savings in electricity can be achieved merely by reducing illumination and turning down thermostats, Netschert points out.

The area of largest potential for industrial energy conservation, according to Netschert, is in the fuels used for heating. "By simply tightening steam leaks, improving boiler efficiency, installing heat exchangers, operating at lower oven temperatures, and so on," he says, "energy savings can be achieved, and at low cost." In the preembargo days of cheap fuel costs, these simple and effective conservation practices were ignored, he notes.

Netschert reminds us of what he said before—that there is little opportunity for immediate energy conservation in a plant where electricity is the main energy component. "If it is an electrometallurgical or electrochemical plant, for example, as in aluminum reduction or chlorine production, there is a fixed relationship between kilowatts and quantity of output," he explains. "A significant reduction of electricity in such cases is done only at a sacrifice in production. And since the plant is intended to produce, you can't count a reduction in the electricity bill as savings when you have to cut production."

Although Netschert acknowledges that "it is extremely difficult to forecast" what the energy conservation gains may be from future new technologies, he ventures "it is conceivable that in certain industries where technological innovation is possible, the gains in the 1980s could equal or exceed those to date. Whether the total energy conservation by all industry will show the same result is another question."

"If we don't prepare to meet our energy needs, the consequences could bring economic growth to a halt and throw us into a depression."

In talking with plant managers around the country, Netschert found that as the supply of natural gas dwindles, industry in many instances is turning to electricity as the preferred alternative. Coal ranks as the least attractive alternative in view of the cost and complications in meeting federal regulations governing the air pollution aspects of coal burning. And the high price and uncertain supply of oil is steering industry away from that fuel.

"At plants using die-casting machines or injection-molding machines for plastic parts, I found a tendency to specify electric heating in machines newly installed or on order," Netschert relates. He found evidence in the glass industry of a turn toward electric melting, and in some automobile assembly plants, the next generation of paint-drying furnaces will use infrared lamps instead of gas.

This apparent "electrification of industry" is happening despite the fact that electricity per Btu is now more expensive than conventional heating sources. Netschert offers an explanation based on his conversations with plant managers." Because electricity is more efficient at the point of use than the fuel it replaces—especially if the substitution is for steam—a plant that substitutes electricity for a fuel is conserving energy, as far as *its* management is concerned." Netschert adds, "Even without a direct cost edge, electricity offers the advantage of throwing the whole burden of the reliability of energy supply onto the shoulders of the friendly local utility, which has the legal obligation to serve. For many plants, it's worth paying an apparent premium for the transfer of this burden."

The demands on the time of a busy executive that serving on EPRI's Advi-

"A fuller public understanding of the energy problem would bring a more balanced appraisal of the conflict between energy production and environmental protection."

sory Council has meant for Bruce Netschert seem not to be a burden he wishes to transfer. In addition to being vice chairman of the Council, he's chairman of the Committee on Power Sources and Uses. Says Netschert, "All the people on the Council do some schedule-juggling to fit in time for Council work. My feeling is if you're going to accept a responsibility like this, do it. I find it interesting. If I didn't like it, I'd quit."

Bruce C. Netschert is an economist, specializing in the fields of energy and mineral resources. As vice president of National Economic Research Associates, Inc., Netschert supervises research in a broad range of subjects, but with a personal emphasis on fuel supply/demand forecasting. He is often called on to testify as an expert witness before state and federal courts, regulatory agencies, and at congressional and departmental hearings.

Before taking over direction of NERA's Washington office in 1961, Netschert spent six years as a senior research associate with Washington-based Resources for the Future, Inc., working on supply forecasts of the major metals and of fuels and energy sources, including nuclear and solar.

Netschert was in government between 1951 and 1955, serving as a commodity-industry analyst for the Bureau of Mines; as a staff member of the President's Materials Policy Commission; as a consultant to the National Securities Resources Board and its successor agency, the Office of Defense Mobilization, assisting in the formation of stockpile and mineral industry mobilization policy; and as branch chief in nonferrous metals and nonmetallic minerals analysis for the Central Intelligence Agency.

Among the books Netschert has published are *The Future Supply of the Major Metals* (with H. Landsberg, 1961); *Energy in the American Economy, 1850–1975* (with Sam Schurr, 1960); and *The Future Supply of Oil and Gas* (1958). He is a frequent contributor to professional journals and trade magazines and for several years has written the article on "Fuels and Power" in the *Encyclopaedia Britannica Book of the Year.*

Netschert is a member of the American Economic Association and the American Institute of Mining, Metallurgical and Petroleum Engineers, and is a Fellow of the Geological Society of America and the Institute of Petroleum (London). He holds a doctorate in economics from Cornell.

Netschert is vice chairman of EPRI's Advisory Council and chairman of the Committee on Power Sources and Uses.

Utility System Models

Six utility system models have been developed and are ready for use in EPRI's technology assessment studies. The models will permit the study of different utility operating sensitivities, especially in technology improvements, equipment characteristics, and fuel scenarios.

Preparation of utility system models for use in EPRI's program planning and technology assessment functions has been completed, and the models are now available for use.

Under contract for a technology planning study, Power Technologies, Inc., synthesized the data bases for six idealized electric utility systems that are broadly representative of utilities in various regions of the United States. The models are not, however, exact representations of any individual utility, power pool, interconnection, or region of the country.

Data used in preparing the models were gathered from published materials available to the public. Federal Power Commission data, EEI publications, and reports of the Electric Utility Reliability Councils were examined. Data typical of installations for existing utilities and utility equipment were developed; future expansion plans and equipment options were identified; and from these, the model utilities were synthesized so as to be representative of various types of utilities in the mid-1980s.

The six models highlight some of the differences among electric utilities in the United States, such as:

- Generation mix
- Fuel resource availability
- Load characteristics
- Load density
- Transmission network characteristics

The accompanying chart gives the principal characteristics of the six models.

The model systems are intended for technology assessment studies to determine the technical and economic feasibility of new technologies or technology improvements. The models will also be used to assess evaluation methodology.

During the development process, a case study was performed, which demonstrated that the model systems can be used for the intended purposes. They are being used or are planned for use in several EPRI research areas. The model systems will:

- Provide the level of detail necessary for the adequate simulation of utility conditions
- Allow the same programs and methodology used by utility system analysts for evaluating new technologies to be used to analyze research and development requirements
- Provide for realistic assessments of regional differences, without implications about specific systems

Different utility systems have different operating sensitivities. The models permit these sensitivities, especially in regard to the technology improvements, equipment characteristics, and fuel scenarios to be studied. The model systems range in size from approximately 20,000 MW to 50,000 MW of installed generation and represent from 5000 to 20,000 circuit miles of transmission.

The final project report will be available through the National Technical Information Service (NTIS). The report will describe the data base, characteristics, and other features incorporated in the model systems.

The data will also be available on magnetic tape. For information on ordering this tape, contact H. Zaininger, Planning Division, EPRI.

SYSTEM CHARACTERISTICS

System	Generation (MW)	Load (MW)	Transmission (mi)	Comments
A	53,500	44,000	15,500	A summer-peaking system; largely coal and nuclear baseload generation; predominantly 345-kV and lower transmission network, with expanding 500-kV and 765-kV transmission development; medium (average) transmission distance between generation and loads. (This implies that loads are evenly distributed throughout the service territory.)
B	46,000	38,000	21,000	A winter-peaking system with high summer peaks; significant hydro generation; predominantly 500-kV and 230-kV transmission network; long (average) transmission distances between generation and loads. (This implies that generation is remote from loads.)
C	22,000	16,500	13,500	A summer-peaking system; largely coal and nuclear generation; predominantly 345-kV and lower transmission; generation very remote from loads
D	32,000	26,000	5,000	A summer-peaking system; predominantly oil generation, with some nuclear and coal; predominantly 500-kV and 230-kV transmission network; dense load distribution, with generation near loads
E	45,500	37,000	12,500	A summer-peaking system; predominantly gas generation, with new coal and nuclear; predominantly 345-kV and lower transmission network with some 500-kV; uniform load distribution
F	32,000	26,000	13,000	A summer-peaking system with high winter peaks; mostly oil and nuclear generation; 500-kV and lower transmission network; uniform load distribution

At the Institute

UTILITIES EXPRESS CAUTIOUS INTEREST IN LEAD-ACID BATTERIES

A second workshop to examine the prospects of using lead-acid batteries for bulk energy storage in electric utility systems was held in Washington, D.C., December 9 and 10. Sponsored by EPRI and ERDA, the workshop capped two years of studies in a national research effort to investigate utility applications for lead-acid batteries.

A similar workshop was held in November 1975 (EPRI JOURNAL, March 1976, p. 47). At that time workshop participants concluded that although the projected costs of lead-acid battery technology appeared too high for broad market penetration, further investigation was needed to determine whether the technology might meet specific utility needs.

During 1976, EPRI and ERDA expanded battery cost and design studies and initiated a series of application studies conducted by Public Service Electric and Gas Co., New Jersey. Results of the research were presented at the December workshop, which was attended by representatives of major U.S. battery manufacturers, 12 electric utilities, EPRI, and ERDA.

"Information gathered during the past year again seems to indicate that the cost of lead-acid batteries would be above what is generally considered affordable by utilities," explained Jim Birk, project manager in EPRI's Energy Storage Program. Total probable cost of a 5-hour lead-acid battery is estimated at $520/kW. Detailed cost estimates are given above.

	5-hour (optimistic)	*5-hour (probable)*
Battery ($/kWh)	39	55
Converter ($/kW)	55	70
Balance of plane ($/kWh)	25	30
Total cost ($/kW-dc)	375	495
Total cost ($/kW-ac)	395	520
System efficiency (%)	69	72
Battery life (cycles)	1750	2000
Replacement battery ($/kWh)	34	41
Operation and maintenance (mills/kWh)	0.3	0.3

"However, studies completed this year by Public Service Electric and Gas Co. have identified three conditions that could make lead-acid batteries economically competitive," Birk noted.

These expansion studies concluded that utilities could realize savings by installing lead-acid batteries if (1) acquisition of a large number of transmission facilities could be deferred; (2) large amounts of off-peak nuclear or other base fuel could be used for charging the batteries; and (3) the cost differential between the fuel used to charge the batteries and the fuel used in conventional combustion turbines would be substantial.

"It's not inconceivable that these three conditions could exist in several specific utility systems," stated Birk.

In addition to cost estimates, information was presented at the seminar on battery design, environmental issues, and siting.

"We have learned that the lead-acid battery can be built to meet the technical and siting requirements of the utility industry," Birk stated. "The recommended system design comprises about a thousand closed, water-cooled cells weighing up to about two tons each. Economics and utility requirements suggest a multi-tier configuration of these cells housed in a specially engineered building. A 100-MWh battery of this configuration can be built to occupy a building about two-and-a-half stories high, covering less than half an acre of land."

Utility representatives present at the workshop expressed cautious interest in the lead-acid battery. They rated its prospects in third place when compared

with other near-term alternatives. Load management and compressed-air storage were rated higher than lead-acid batteries in terms of possible utility application; underground pumped-hydro and central station thermal storage were rated lower.

Five of the 12 utilities indicated "possible interest" in a 5-hour, $425–$575/kW lead-acid battery; 6 utilities indicated that a demonstration plant is warranted now.

The next step, according to Birk, is to determine on a case-by-case basis whether there is indeed sufficient interest among utilities in a full-scale demonstration. If there is, Birk noted, EPRI and ERDA will make plans to go ahead with the plant. That decision is to be reached by this summer.

Symposium on FCLs and PCBs

A recent symposium on R&D in fault current limiters and power circuit breakers helped utility representatives communicate their needs in these areas to research investigators. At the same time, the investigators were able to update utility officials on their research.

The three-day symposium was sponsored by EPRI and the Electrical Engineering Department of the State University of New York at Buffalo. Participants included most of the principal investigators in the U.S. and abroad who are working in arc physics, power circuit breakers, and fault current limiters. The 120 engineers and scientists in attendance represented manufacturers, universities, consulting engineering firms, government laboratories, and 26 electric utilities.

Japanese Battery Specialists Visit EPRI

An official Japanese battery team visited EPRI recently during a trip to the U.S. hosted by ERDA. A similar U.S. team visited Japan last year and the two countries are finalizing negotiations for a bilateral information exchange agreement on battery energy storage technology.

Jim Birk, project manager in EPRI's Energy Storage Program, is part of the U.S. team working on this agreement. He notes that the information exchange between EPRI and the Japanese energy community has proved mutually beneficial in the area of battery research, even though the respective programs emphasize different applications for this new technology.

"Japan's main interest in battery technology is for use in electric vehicles," Birk explained. "The government and industry have been mobilized to research, develop, and demonstrate the advanced technology for electric vehicles. It is a high-priority item on the national agenda and has been under way since 1971. In fact, Japan may very well be the first country to introduce a commercial electric vehicle."

In contrast, EPRI's research program emphasizes the use of batteries for leveling the power loads of electric utilities. Many technical and materials problems, however, are common to both types of battery application.

Jim Birk (standing), EPRI project manager in the Energy Storage Program, explains the Institute's battery research and development projects to a group of Japanese battery specialists who recently visited EPRI. They are (from left): Shinichi Ikari, Shin-Kobe Electric Machinery Co., Ltd.; Yoshizo Miyake, Osaka Government Industrial Research Institute; Seisaku Hattori, Yuasa Storage Battery Co., Ltd.; H. Ikeda, Sanyo Electric Co.; and Yoshiharu Shiroyama, Japan Storage Battery Association.

Birk concludes that this new relationship can help open "new channels of communication" that will bring both countries closer to their goals in battery development.

R&D Requirements of Small Electric Utilities

What are the key economic, policy, and technical factors that affect the planning and operation of small utilities? Which of EPRI's programs are especially beneficial to small utilities and how can the value of such programs be increased?

Finding answers for such questions was the purpose of an EPRI workshop held in December and attended by representatives from a number of small public utilities.

The utilities represented at the meeting, all members of the American Public Power Association, expressed a strong interest in strengthening communications between EPRI, municipal utility staffs, and the governing boards of the utilities, especially in such research areas as fuel cells, gas turbines, solar energy, solid waste burning for electricity, energy storage, and dispersed generation technologies.

Special interest was expressed in several areas of EPRI's Distribution Program: corrosion mitigation; equipment development for underground distribution systems; improved lightning arresters; publication of cable and transformer loading guides; and research on the potential of solid-state protection, control, and metering devices.

Reviewing some of the materials generated at a recent workshop on the R&D requirements of small electric utilities are (from left) A. Floyd, science advisor to the City of Burbank Public Service Department; P. Patino, R&D director, Public Service Company of Colorado; E. Gillis, project manager for fuel cell development, EPRI; W. Canney, administrator, Lincoln, Nebraska, Electric System; and K. Klein, assistant to the director of the Electric Energy Systems Division, ERDA.

Agreement Signed With Japanese Research Group

A formal agreement was signed recently by EPRI and the Central Research Institute of Electric Power Industry (CRIEPI), in Japan, that provides for technical information exchange and mutual cooperation in electric power R&D.

CRIEPI is the central and general research agency of Japan's electric power industry. The agreement covers information exchange in the areas of fossil fuels, energy management and utilization technology, new energy resources, electrical systems, energy analysis, environmental assessment, and nuclear power. It also provides for joint research programs.

Similar exchange agreements have been reached with the Central Electricity Generating Board, U.K.; Electricité de France; the Federal Ministry for Research and Technology, Federal Republic of Germany; and the State Power Board, Sweden.

Representatives of EPRI and the Central Research Institute of Electric Power Industry (CRIEPI) work out some of the final details of an information exchange agreement signed last December. Shown here (from left) are W. Endo, fellow research engineer for CRIEPI Nuclear Power; E. Umezu, CRIEPI director of planning; O. Sakurada, manager of CRIEPI's planning section; E. Zebroski, director of EPRI's Nuclear Systems and Materials Department; R. Rudman, director of EPRI's Planning Department; and M. Levenson, director of EPRI's Nuclear Power Division.

Project Highlights

Bottlenecks May Hamper Coal Shipments

The projected increase in the use of coal over the next 10 years may be hampered because of bottlenecks on congested rail and waterways.

An EPRI study found that although congestion does not pose absolute limits on coal movements, coal being transported in 1985 from Wyoming to West Texas, for example, may occasionally have to be sent by a circuitous route—perhaps through Kansas instead of Colorado. The result, of course, would be higher costs.

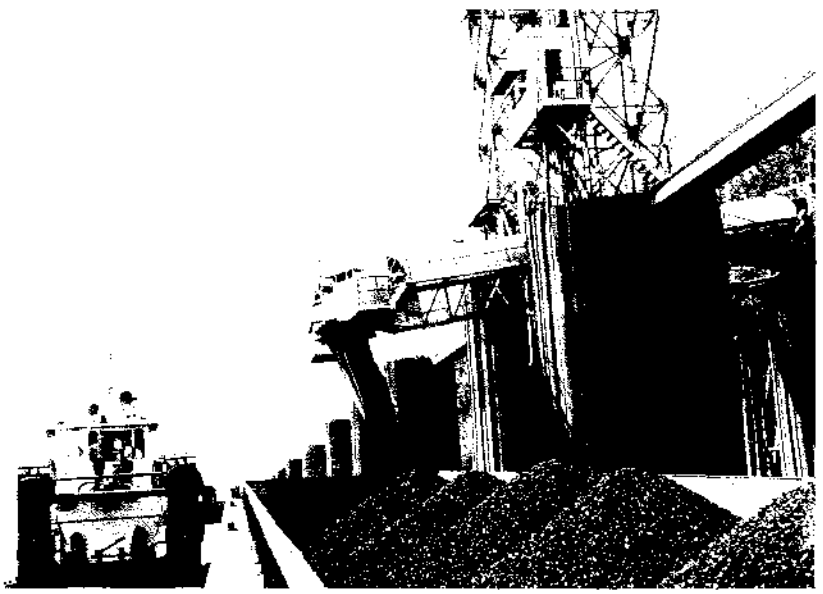
According to EPRI officials, the report may be somewhat optimistic in that it assumes railroads will keep roadbed and rolling stock in good condition, that new rolling stock will be purchased as needed, and that conditions on waterways will be normal.

Under the highest coal production case considered by the report, by 1985 the potential coal movement from mines to destination plants and ports could reach 18.6 million carloads per year at an average distance of 430 miles per carload. The report notes that this level of coal traffic is 156% greater than all 1973 coal shipments and 359% greater than 1973 coal shipments by rail.

The report further states that the potential movement of other commodities by rail could reach 29.4 million carloads annually, with an average distance of 600 miles per carload. This represents a 30% increase over 1973 movement.

"The combination of these traffic demands on railroad capacity would overload many of the network links on the shortest path from origin to destination," the report asserts, stating that of the 16 most critical river, mountain, or other barriers examined, 11 have one or more overhead links.

A barge is loaded with coal at the Yankeetown dock on the Ohio River near Evansville, Indiana. Several such barges will be lashed together in a single tow to deliver thousands of tons of coal. *Photo courtesy National Coal Association.*



By providing a better understanding of coal transportation capabilities, the EPRI study is important to utilities in making planning decisions. In addition, coal transportation affects the ability of utilities to comply with FEA directives to use coal for power production in place of oil and gas.

The study was conducted under a contract with Manalytics, Inc., of San Francisco, with much of the research based on data and computer services provided by the Federal Railroad Administration (FRA).

The report concludes by recommending that new cost models be developed for railroad and water transportation and for intermodal transfer of coal. At the same time, the report suggests that such models be used in conjunction with the FRA model to evaluate the total costs of alternative routing. The value of direct-route capacity improvements, such as increased rail capability at crucial points and bigger locks at ports, can then be determined.

New Coal Liquefaction Pilot Plant

Another energy source may soon be available for producing electricity if tests at a $90 million coal liquefaction pilot plant in Catlettsburg, Kentucky, are successful.

December 15 marked the start of the plant's construction. When completed, tests will be run on a process developed by Hydrocarbon Research, Inc., to convert coal into clean-burning liquid fuel. The pilot plant is part of a $178 million government-industry research program to commercially develop what is called the H-Coal process.

ERDA plans to fund $142 million of the $178 million program. Other sponsors include EPRI, the Commonwealth of Kentucky, Standard Oil Co. of Indiana, Ashland Oil, Inc., Mobil Oil Corp., and Conoco Coal Development Co.

Citing the uncertainty over future supplies of imported fuel oil and the dwindling supplies of U.S. natural gas and petroleum, EPRI's Ronald Wolk noted that the H-Coal process, as well as other developing liquefaction technologies, "will help ensure the electric utility industry an adequate supply of domestic liquid fuels that are storable and clean."

Participating in the coal liquefaction pilot plant ground-breaking ceremony are (from left) Seymour B. Alpert, director of fuels, Advanced Fossil Power Systems Department, EPRI; John E. Kasch, vice president, Standard Oil Co. of Indiana; Robert E. Yancey, president, Ashland Oil, Inc.; John D. Sudbury, vice president, Conoco Oil Corp.; Philip C. White, assistant administrator for fossil fuels, ERDA: and Frank N. Fagan, manager of process engineering, Mobil Oil Corp.

Wolk, the manager of EPRI's Clean Liquid and Solid Fuels Program, stated that coal liquids may "ultimately" be used as a high-quality fuel for utility boilers, although their main use will probably be for gas turbines. Today's gas turbines, used primarily to meet a utility's peak times of power demand, rely on natural gas or petroleum.

In addition to serving as a substitute for scarce fossil fuels, coal liquids (which can be transported by pipeline) could alleviate some of the problems normally associated with siting power plants.

At the same time, certain processing approaches produce very clean products (low in sulfur and other pollutants) so utilities may be able to avoid buying expensive pollution control systems for some fossil fuel power plants.

Geothermal Energy Use

A new EPRI study was announced recently that will increase the prospect of using underground hot water resources for power production. Specifically, the study will help researchers determine whether the hydrocarbon turbine generators now used by the petroleum industry can be manufactured in sizes large enough for commercial electricity production.

According to Vasel Roberts, EPRI program manager for geothermal energy, hot water resources "may be an important supplemental energy source, especially in the Southwest."

Much of the hydrothermal energy in the U.S. cannot be used in conventional turbine generators because of its low-to-moderate temperature characteristics. Under an EPRI contract, Elliott Co., a division of Carrier Corp., will determine whether scaled-up versions of hydrocarbon turbine generators can be economically built to make use of lower-temperature hydrothermal energy.

The technology would call for the turbines to exchange the heat from the underground resources to boil hydrocarbon fluids for electricity. The conversion process envisioned uses a binary-cycle conversion process—so called because two fluids, the hydrothermal brine and the hydrocarbon liquid, are used.

The results of this design study will help support the development of a 50-MW hydrothermal demonstration plant, scheduled for completion in 1980.

There are several forms of geothermal energy, including hydrothermal convection systems, geopressure, dry hot rock, magma, and normal gradient. The most abundant form that may yield to present drilling and power conversion technologies is found in hydrothermal convection systems, which occur when the heat of the earth, in combination with running water, forms natural underground dry steam and hot water reservoirs at high pressure. Hot water reservoirs are much more common than underground dry steam, which is rare.

Research on UHV Transmission

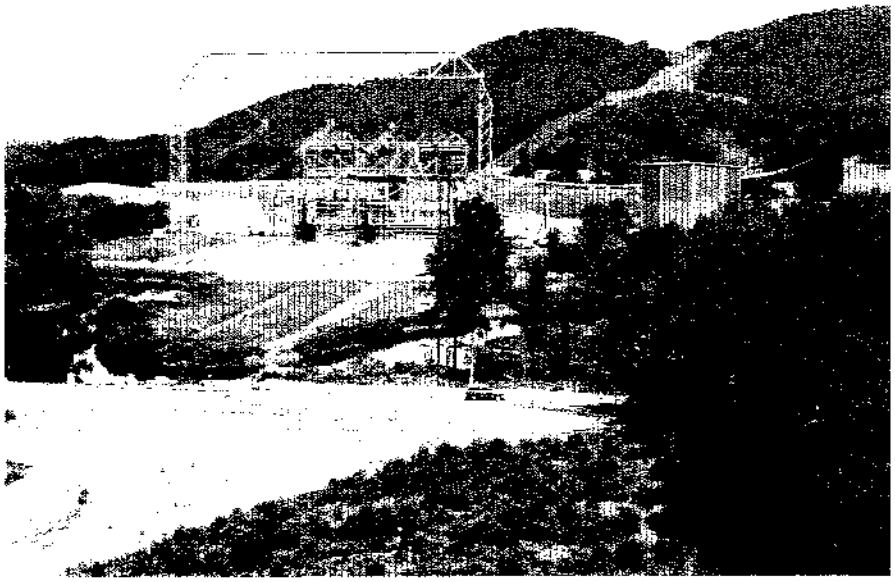
A $3.8 million contract with General Electric Co. will extend for three years a research project on ultrahigh voltage (UHV) transmission technology. The work is being carried out by General Electric's Large Transformer Business Division in Pittsfield, Massachusetts. EPRI has supported the research since 1974 and $4.8 million has been expended thus far.

"The purpose of the project is to provide the electric utility industry with sound engineering data that will give utilities the option to include UHV transmission in the design of their power systems," stated Frank Young, manager of EPRI's Overhead Lines Program.

Young explained that UHV transmission conserves space and increases the efficiency of the power system. He noted that the amount of power a transmission line can carry increases with the size of the voltage. Higher voltages allow more power to be transmitted over the same amount of space.

As a result of the first phase of the project, researchers have demonstrated that UHV transmission is technically feasible—that power lines from 1100 kV to 1500 kV can be engineered and constructed. (The maximum ac transmission voltage in the U.S. today is 765 kV.) Another achievement has been the development and verification of electric field measurements and prediction techniques that are being used nationwide by utilities.

A new phase of research has begun in Pittsfield, Massachusetts, in an ongoing EPRI project to develop UHV transmission technology. This overview of Project UHV shows the first tower of the three-phase, 1500-kV test line, the transformers, and the fog chamber, which is 80 ft high.



The third major accomplishment of the first phase was the publication in 1975 of the *Transmission Line Reference Book—345-kV and Above,* which gives data and design rules for conductor selection, insulation requirements, and electric fields. This will be updated in 1979 as a part of the current study.

Objectives for the new phase of the project include developing data on the corona phenomena of UHV transmission (radio interference and audible noise); studying insulation requirements for transmission lines, with particular emphasis on the contamination performance of insulators; and extending the study into electric field effects of UHV transmission.

Safer Power Transformers

The start of a new research project to develop safer power transformers was announced last month. The objective of the $2 million project is to develop gas-insulated, vapor-cooled transformers that compare economically and are more fire resistant than conventional oil-filled transformers.

According to Robert Tackaberry, the EPRI project manager for the study, this development is especially important because of the recent government ban on polychlorinated biphenol—a compound that was widely used in transformers but now banned because of its nonbiodegradable characteristics.

The project is being cooperatively funded by EPRI, Niagara Mohawk Power Corp., Empire State Electric Energy Research Corp., and Westinghouse Electric Corp., who will conduct the actual research.

It is anticipated that the project will culminate two years from now in the construction and field-testing of gas-insulated, vapor-cooled transformers in three sizes.

EPRI Negotiates 62 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP109-3	Development of the Sodium-Antimony Trichloride Battery for Utility Application	1 year	304.8	ESB, Inc. *J. Birk*
RP236-2	Safety Studies of Fusion-Fission Power Reactors	1 year	90.0	University of California at Los Angeles *N. Amherd*
RP244-2	Engineering Review and Evaluation—Combustion Engineering Co. Gasification Plant	6 months	34.7	Bechtel, Inc. *H. H. Gilman*
RP411-2	Process Engineering Evaluations of Various Coal Liquefaction Processes	6 months	269.2	Ralph M. Parsons Co. *R. Wolk*
RP458-2	Phase II—Application of Advanced Materials and Fabrication Technology to Letdown Valves for Coal Liquefaction Systems	9 months	81.4	Battelle, Columbus Laboratories *H. Lebowitz*
RP475-2	Central Receiver Open-Cycle Gas Turbine Solar Power Plant	17 months	375.2	Black & Veatch Consulting Engineers *J. Bigger*
RP630-3	Process Control Demonstration Program—Phase II	6 months	29.0	Radian Corp. *T. Morasky*
RP725-2	Advanced Electrostatic Precipitator Pilot Plant	20 months	349.0	Kaiser Engineers *O. Tassicker*
RP725-4	Advanced Particulate Control Development and Test Facility	14 months	373.4	Joy Manufacturing Co. *O. Tassicker*
RP725-6	Advanced Particulate Control Facility	21 months	159.6	Stone & Webster Engineering Corp. *O. Tassicker*
RP775-1	Coal Slurry Feed Pump Development—Liquefaction	1 year	246.1	Rockwell International Corp. *H. Gilman*
RP778-1	Exxon Donor Solvent (EDS) Coal Liquefaction Process Development	18 months	2150.0	Exxon Research and Engineering Co. *R. Wolk*
RP779-5	Short Residence Time Coal Liquefaction	8 months	69.5	Battelle, Columbus Laboratories *W. Rovesti*
RP779-7	Autoclave Studies on Coal Solution	6 months	14.9	Suntech, Inc. *H. Lebowitz*
RP783-1	State-of-the-Art Review of Stack Treatment Techniques for NO_X Control	6 months	43.9	Battelle, Columbus Laboratories *D. Teixeira*
RP786-2	By-product/Waste Disposal for Flue Gas Cleaning Processes	1 year	198.9	Radian Corp. *T. Morasky*
RP909-1	Water Management in Coal-fired Power Plants	11 months	74.7	Water Purification Associates *R. Jorden*
RP918-1	An Assessment of the Fuel Cell's Role in Small Utilities	13 months	133.4	Burns and McDonnell *A. Fickett*
RP926-1	SHAC Computer Program Extension and Documentation	9 months	64.9	Arthur D. Little, Inc. *J. Cummings*
RP928-1	Preliminary Design of Axial Flow Hydrocarbon Turbine/Generator Set	6 months	58.3	Elliott Co. *V. Roberts*
RP929-1	Geothermal Reservoir Assessment Techniques	1 year	86.6	Geonomics, Inc. *V. Roberts*
Nuclear Power Division				
RP249-2	Zircaloy-Steam Oxidation Kinetics	18 months	100.0	Worcester Polytechnic Institute *H. Ocken*
RP311-3	The Influence of Combined Environmental Effects on the Stress Corrosion Cracking of Welded Stainless Steel Piping	2 years	220.9	Battelle, Columbus Laboratories *R. Smith*
RP497-4	Explicit Heterogeneous 2-D CPM	8 months	48.0	AB Atomenergi, Sweden *B. Zolotar*
RP519-4	Documentation of Operating Data From Light Water Power Reactors for Methods Verification	1 year	26.3	Babcock & Wilcox Co. *B. Whitesel*
RP771-1	Analysis of Reliability/Availability Data Systems	1 year	390.1	Stone & Webster Engineering Corp. *W. Lavelle*
RP810-1	Soil-Structure Interaction	1 year	349.6	University of New Mexico *C. Chan*
RP810-2	Soil-Structure Interaction	1 year	171.6	Weidlinger Associates *C. Chan*
RP810-3	Soil-Structure Interaction	1 year	143.0	John A. Blume & Associates, Engineers *C. Chan*
RP810-4	Soil-Structure Interaction	1 year	60.5	Fugro, Inc. *C. Chan*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP810-5	Soil-Structure Interaction	18 months	151.0	Systems, Science and Software *C. Chan*
RP819-1	BWR Radiation Assessment and Control	42 months	987.1	General Electric Co. *R. Shaw*
RP886-1	Neutron Embrittlement of Reactor Pressure Vessel	36 months	248.5	Fracture Control Corp. *T. Marston*
RP888-1	Two-Phase-Flow Analyses Related to Reactor Safety	1 year	143.4	Jaycor, Inc. *L. Agee*
RP889-1	Development of a System Transients Simulator	2 months	150.0	Energy Inc. *L. Agee*
RP895-2	Power Shape Monitoring System	2 months	10.0	Scandpower, *F. Gelhaus*
RP895-3	Power Shape Monitoring System	2 months	9.7	Nuclear Associates International Corp. *F. Gelhaus*
RP895-4	Power Shape Monitoring System	2 months	9.7	Nuclear Services Corp. *F. Gelhaus*
RP900-1	HTGR Steam Cycle Technology	3 months	63.0	NUS Corp. *M. Lapides*
Electrical Systems Division				
RP792-2	Wind-induced Conductor Motion	15 months	68.1	Commonwealth Associates *K. Griffing*
RP792-4	Wind-induced Conductor Motion	1 year	30.9	Washington State University *K. Griffing*
RP849-1	Determining Load Characteristics for Transient Performances	45 months	399.9	General Electric Co. *T. Yau*
RP849-3	Determining Load Characteristics for Transient Performances	21 months	200.3	University of Texas at Arlington *T. Yau*
RP850-30	Field Demonstration of Communication Systems for Distribution Automation	26 months	1324.0	Westinghouse Electric Corp. *W. Blair*
Energy Analysis and Environment Division				
RP803-3	Analysis of U_3O_8 Production Costs by Solution Mining	5 months	44.2	S. M. Stoller Corp. *R. Urbanek*
RP806-1	Generation System Reliability Analysis for Future Cost-Benefit Studies	14 months	74.8	General Electric Co. *J. Karaganis*
RP858-1	Removal of Pollutants From Power Plant Plumes by Precipitation	1 year	68.3	Battelle, Pacific Northwest Laboratories *C. Hakkarinen*
RP868-1	Cataloging and Evaluating Coal Resource Information	1 year	90.0	ICF, Inc. *J. Platt*
RP869-1	Effect of Risk on Prices and Quantities of Energy Supplies	1 year	50.0	Microeconomics Associates *A. Halter*
RP870-1	Analysis of ERDA and USGS Uranium Program Data	2 years	199.1	Dames & Moore, Inc. *J. Platt*
RP871-1	Estimation Methodology for Energy Supply From Natural Resources	9 months	50.0	Massachusetts Institute of Technology *A. Halter*
RP936-1	Socioeconomic Impact of Power Generation: A Planning Study	6 months	44.6	Westinghouse Electric Corp. *R. Wyzga*
RP940-1	The Relation of Air Pollution to Mortality, New York City	2 years	210.0	Albert Einstein College of Medicine of Yeshiva University *R. Wyzga*
RP943-1	Long-Term Residential Load Forecasting	8 months	46 5	Econometric Research Associates, Inc. *A. Lawrence*
RP943-2	Forecasting Residential Loads With Time-of-Day Rates	1 year	66.7	Charles River Associates *A. Lawrence*
RP945-1	Methodology for Early Evaluation of New Energy Processes	15 months	47.9	Research Foundation of City University of New York *R. Urbanek*
RP951-1	Impact of Coal Preparation on Eastern Coal Supply	15 months	53.0	West Virginia University *T. Browne*
RP953-1	Probable Distribution of Effluent Sources From Energy Supply and Conversion	1 year	94.9	Johns Hopkins University *R. Michelson*
RP954-2	Initiation of Supply, Demand, and Environmental Integration	7 months	50.2	Data Resources, Inc. *J. Karaganis*
RP954-3	Initiation of Supply, Demand, and Environmental Integration	7 months	49.1	Stanford Research Institute *J. Karaganis*
RP954-4	Initiation of Supply, Demand, and Environmental Integration	7 months	48.8	National Bureau of Economics Research, Inc. *J. Karaganis*
RP1017-1	Analysis of Dry Rock Geothermal Energy Utilization	15 months	69.5	University of New Mexico *R. Urbanek*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

COAL CLEANING

The electric power industry is the primary user of coal in the U.S. EPRI estimates that by the year 2000 about 44% of the primary energy source for electric power generation will be coal, about 80% of which will be fired directly in boilers. The ability to meet air quality standards is the principal concern in the use of coal. For direct firing there are three options for meeting sulfur oxide control regulations: flue gas desulfurization, fluidized-bed combustion (CO combustion), and coal beneficiation.

Flue gas desulfurization and fluidized-bed combustion can be designed to be independent of the coal source. The usefulness of coal beneficiation, however, depends on the nature of the coals burned. Coal properties and ash content directly affect the level of sulfur reduction that can be achieved by existing physical coal-cleaning methods, by improved physical coal-cleaning methods, or by chemical coal-cleaning processes.

It is estimated that total coal demand will increase from 657 million tons in 1975 to 1.04 billion tons in 1985 and to 1.28 billion tons in 1990 and that utility coal demand will increase from 405 million tons in 1975 to 710 million tons in 1985 and 800 million tons in 1990.

Approximately 97% of the western coal delivered to utilities in 1975 had a sulfur content of 1.0% or less. About 23% of eastern shipments was of the same quality. However, in the central U.S., 92% of the shipments to utilities had a sulfur content of 2.0% or more.

The low sulfur content of western coals may be misleading—its relatively low heating value means that only a small fraction contains less than 0.6 lb sulfur per 10^6 Btu, one projected standard for 1985. In the East, half the low-sulfur coal is used for metallurgical applications, so very little steam coal that meets the EPA's new-source performance standards (NSPS) for sulfur will be available. In 1974, only 15% of the coal produced conformed to NSPS. The picture is equally bleak for existing power stations, most of which fall under state implementation plans for sulfur control. The U.S. Bureau of Mines recently reported that half the coal burned by electric utilities in FY75 did not conform to environmental regulations (*Effects of Air Quality Requirements on Coal Supply*, USBM Contract J0155164).

Coal beneficiation research will improve this picture by providing the means to remove sulfur from coal and produce an acceptable fuel. The Commerce Technical Advisory Board recently estimated that moderate coal cleaning could reduce the capital cost of scrubbing equipment by more than $25/kW. EPRI estimates that perhaps as much as 75% of the high-sulfur coal production from the central U.S. could be processed to produce NSPS coal at a price less than, if not equivalent to, that of flue gas cleaning.

The EPRI coal-cleaning program focuses on assessing the validity of this estimate. Emphasis is on sulfur reduction with an overall improvement in both cleaning technology and cost-benefit ratio. While a detailed coal-cleaning program plan is currently being developed, several projects are under way, laying groundwork for further EPRI research.

An assessment of coal preparation technology by Gibbs & Hill, Inc., (RP466) will provide a comprehensive, authoritative, and up-to-date description of coal preparation technologies and the economics of their application in direct combustion or in coal conversion to gaseous and liquid products for power generation. The study is now nearing completion and a report will be published in the first quarter of 1977.

Atlantic Richfield Co. has been testing its chemical process for removal of pyritic and organic sulfur from coal under EPRI sponsorship (RP833). The purpose of this project is to characterize the ability of the process to remove both pyritic and organic sulfur from U.S. coals; to predict the effect of the process on the performance of the cleaned coal in utility boilers; to estimate the economics of the process; and to prepare a conceptual design of a continuous integrated coal-cleaning plant. This project will be continued during 1977.

A technical planning study (TPS 76-645) by Kaiser Engineers identified promising areas of physical coal preparation where further development could lead to improved production of high heating value, low-sulfur, low-ash coal at optimal cost. The final report is being reviewed by the EPRI staff.

An EPRI R&D planning workshop on coal-cleaning research was recently held in Palo Alto and was attended by representatives of universities, engineering firms, utilities, and contractors involved in coal preparation plant design. The workshop recommendations will be documented as a basis for future R&D projects to be undertaken by EPRI.

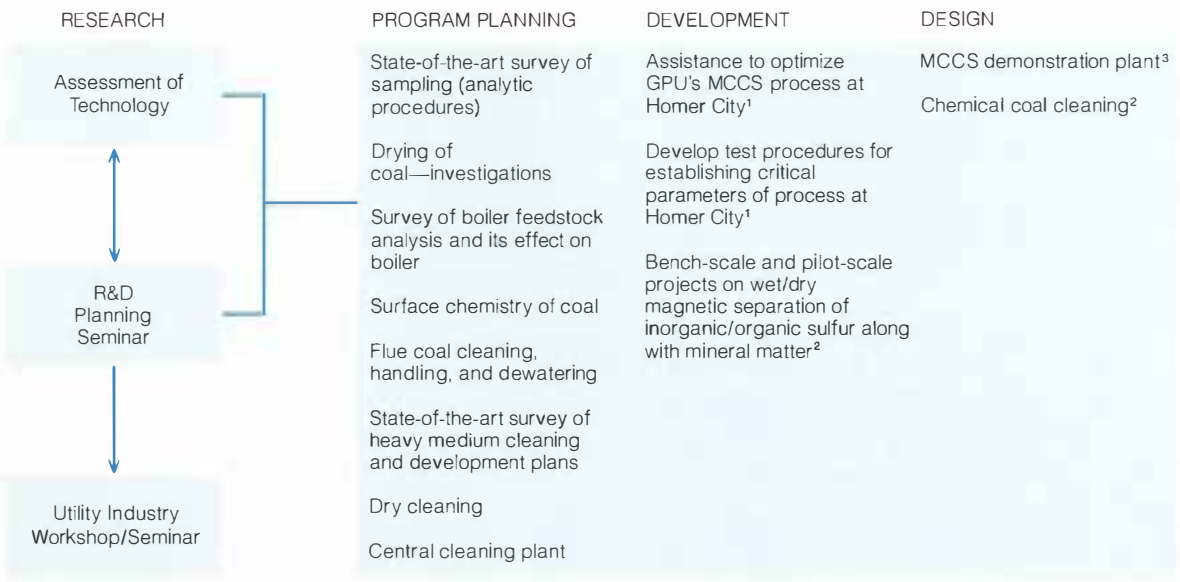
Projects selected from the recommendations and subsequent discussions with utility members are being evaluated as program topics (Figure 1). A project to assess the technical and economic feasibility of four magnetic separation techniques for removing pyrite from coal was approved in November. The results from each of the methods will be compared, and those having the greatest potential for successful commercial application will be pursued.

EPRI is also developing agreements with other organizations, such as ERDA, EPA, and USBM, to mutually develop and test processes and techniques for coal cleaning. This group is expected to produce a national program group plan in coal preparation. *Project Manager: Stan Venkatesan*

ENERGY UTILIZATION AND CONSERVATION TECHNOLOGY

This program was established last May to provide a focal point within EPRI for R&D on technologies that can enhance conservation and efficient use of electric energy. A series of internal discussions and the findings of a recent workshop have led to the establishment of the preliminary plan that is described below. (Workshop recommendations are shown in Table 1.) In view of the importance of this area, and recognizing the electric utilities' growing involvement in many conserva-

Figure 1 Coal-cleaning technology. There are certain areas in which viable technology must be developed to design a commercial plant. Extensive experimental work has been done in several of these areas, but in most cases its value is only qualitative.



[1]1976–77 projects partly funded by EPRI
[2]EPRI funded
[3]Under construction by General Public Utilities Corp.; EPRI's involvement will be in testing and evaluation.

tion programs of their own, a key aspect of EPRI's program strategy will be to seek broad industry inputs and reviews. Together with the results of specific scoping studies initiated in 1976–77, these inputs will form the basis for establishing a more detailed program plan.

Three broad goals have emerged for the Energy Utilization and Conservation Technology Program. The first goal is to advance the development, demonstration, and acceptance of technologies and practices for more efficient use of electric energy in the nation's major consumer sectors. The second goal, closely related to the first, is to achieve improved utility load management that will result in more economical production and use of electric power. The third goal is to develop and demonstrate efficient new uses of electric energy so it can substitute in functions and processes currently supplied by increasingly scarce gaseous and liquid fossil fuels.

All three major thrusts of the program—more efficient electricity use, improved load management, and efficient substitution of electric for gas/oil energy—are of major importance to the utility industry. More efficient use has the potential of reducing electric energy demand by 17%, or about 1500 billion kWh in the year 2000. Associated oil savings are estimated to be between 2 billion and over 150 million barrels annually.

Improved load management, the second area of program emphasis, has potential for major benefits to electric utilities. The two major aspects of load management involve reducing peak loads through demand control and shifting on-peak energy to off-peak periods through energy storage on the customer's side of the meter. The first aspect is significant but difficult to quantify; the second has an energy management potential of increasing (coal) baseload capacity factor by 5% (absolute) in the national average.

Technologies and systems (such as heat pumps and electric vehicles) that permit electricity to substitute efficiently for natural gas and oil are urgently needed. Their increasing use will result in nationally significant conservation of scarce resources and will impact electric utilities. Properly designed and integrated into the electricity supply/use systems, they could improve load factors significantly.

A key factor in the success of the program will be its relationship with other EPRI programs, the utility industry, the professional engineering community, industry, and ERDA as the major sources of funding for conservation research and development. Close cooperation with EPRI's Energy Demand and Conservation Program and the Solar Program, including joint definition, funding, and management of selected projects, will be sought. This coordination will be especially important in establishing the information base and in assessing energy conservation and utilization impacts.

The program addresses the major energy demand sectors in three subprograms dealing with residential/commercial, industrial, and transportation applications, respectively. In each subprogram, the general approach will be to:

- Develop as rapidly as possible an improved information and data base that can assist in planning decisions of EPRI and individual utilities
- Establish priorities for subprograms and projects on the basis of the probable nature and magnitude of energy utilization and conservation potential
- Carry out a series of interrelated projects on technology and system development, demonstration and impact analysis

A large number of R&D needs and project opportunities have been identified by the EPRI staff and the participants in the program planning workshop. Several technology projects of agreed high priority are currently under way or are soon to be initiated in the residential/commercial applications subprogram described below. However, detailed subprogram structures will be developed only after completion of initial assessment and scoping studies.

Residential/commercial applications

A number of studies have established that climate control in buildings has the largest potential for improved energy utilization and conservation in the residential/commercial sector. Specific areas identified during the recent program planning workshop as deserving high research, development, and demonstration priority include air conditioning, heat pumps, off-peak air conditioning using "cool" storage, heat storage, integration of heating, ventilating and air-conditioning subsystems, and building design. Heat pump development work is already part of the subprogram.

Industrial applications

The industrial sector has major potential for increased efficiency in electricity use, load management, and energy substitution. Significant efficiency increases appear feasible for major industrial uses (such as electric motors), and in electrolytic as well as other industrial processes.

The technological opportunities and economic constraints for these applications are as yet insufficiently defined, in large part because of the diversity in industrial energy utilization patterns and the consequent difficulties in realistically aggregating the conservation and market potential of improved and new technologies. Accordingly, the initial thrust of this subprogram will be to identify the most promising industrial applications and to establish priorities for EPRI's research and development efforts that properly reflect importance to the utility industry.

Transportation applications

The introduction of electric vehicles could develop into a predictable growing load with prospects for a substantial, positive impact on system load factors, especially as more capable batteries and vehicles become available. In the past, this potential has generated widespread utility interest in electric vehicles, expressed most visibly in the formation of the Electric Vehicle Council.

With passage of the Electric and Hybrid Vehicle Research, Development, and Demonstration Act in 1976, ERDA is prepared to carry out a major electric vehicle program (four years, $150 million). It is important that the electric utility industry participate actively in electric vehicle development and demonstration so that utility concerns (load factor maintenance/improvement, adequacy of distribution system capacity, and overall energy economics) will be considered adequately in ERDA's emerging program. EPRI's transportation applications subprogram will be structured as a focal point for utility industry participation in electric vehicle development and demonstration. *Program Manager: Fritz Kalhammer*

Table 1
RANKING OF ISSUES FOR PLANNING
EPRI CONSERVATION AND TECHNOLOGY PROGRAM

Issues	*Importance* (0 5 10 15 20)
Aspects of Conservation	
Efficient new devices and equipment	15
Load management (kW conservation)	20
Efficient end use (kWh conservation)	20
Sector	
Residential	20
Commercial	18
Industrial	15
Transportation	14
Generic Activity	
Information	
Development	19
Dissemination	19
Technology development	
Improved	19
New	14
Demonstration	
Developmental devices	14
Developmental systems	17
Near-commercial systems	9
Purpose/Type of Information	
State-of-the-art assessment	18
Assistance to utility programs	17
Assistance to utility customers	4
Impact on ERDA programs	13
Inform federal/state regulatory agencies	10
Specific Areas	
Residential/Commercial	
Heat pumps	16
Air conditioning	16
Heat storage	17
"Cool" storage	17
Waste heat recovery	15
Other HVAC components	12
Integrated HVAC systems	15
Load control technology	12
Load control systems	12
Industrial	
Heat pump applications	14
Heat pump technology	15
Motor efficiency	15
Electrolytic processes	8
Industrial process efficiency (small customers)	18

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

PRESSURE BOUNDARY WORK ADVANCING

To ensure the continued safe operation of any component within the nuclear pressure boundary, it is necessary to understand how the materials in that component will behave under both normal and faulted conditions. The goal of this research is to develop and upgrade knowledge of materials properties, fabrication processes, and analytic methods so as to be able to predict materials behavior for realistic plant conditions. The work is divided into three areas: materials characterization, materials methodology development, and analytic procedures.

Materials characterization

Before the detailed design of any engineering structure can be undertaken, the materials used in the structure must be characterized. As an example, for safe design it is not only necessary to understand in fine detail the properties of one "heat" of metal but also to understand the statistical distribution of properties of many production heats. The effects of fabrication, environment, and load cycle, and how they alter the properties of materials throughout a structure's lifetime, must also be known. The objective of projects in the category of materials characterization is to provide statistically valid materials properties that can be applied to ensure safe pressure boundary design.

The phenomenon of crack arrest in reactor pressure vessel steels is being studied by Materials Research Laboratory (RP303). This project is an effort to evaluate the validity of the use of the crack arrest toughness parameter K_{Ia} (the critical stress intensity for crack arrest) to determine and evaluate crack arrest. Preliminary results indicate that the classic fracture mechanics arrest parameter K_{Ia} is not an inherent materials property, as was previously thought, but a function of the loading and geometry of the structure. Further work is under way to determine a suitable parameter for use in engineering analysis of crack arrest phenomena.

RP447 with the University of Missouri is a study of the fatigue crack growth characteristics of pressure vessel steels under realistic conditions of environment and load cycle. This work will investigate the effect of stress, chemical environments, frequency, and wave form on fatigue life. Crack growth information will be obtained under conditions typical of those encountered in service.

The materials properties specifications for irradiated pressure vessel steels are specified by the Nuclear Regulatory Commission in Regulatory Guide 1.99 and in 10CFR-50. Unfortunately, the method of measurement of these materials properties is based on a test that does not measure true resistance to fracture. Furthermore, the accuracy of the data base on which the materials properties limits are based is questionable.

The Naval Research Laboratory and Fracture Control Corp. (RP886) are developing a new irradiated materials data base that will be used to establish new suggested irradiated materials properties design limits.

Materials methodology development

To continue to assure maximum safety of any engineering structure, it is not only necessary to characterize properly the materials involved but also to continue to develop new and improved methodology for describing the behavior of structures that have applied duty loads (both steady state and transient).

An example of this type of methodology development can be seen in the evolution of fracture mechanics from simple linear elastic methods, which are applicable only to elastic behavior (exhibited by large steel structures at room temperature and below). At slightly higher temperatures, plasticity occurs and an elastic-plastic method is required. Ultimately, fully plastic behavior must be addressed to analyze LWR structures at operating temperatures.

It is the objective of this effort to define properly areas that require improved methodology to describe and model operating and faulted conditions encountered in reactor operation. Once the limitations of present techniques are understood, projects will be undertaken to improve the analysis and modeling methodology.

The potential cost to the nuclear industry from shutdowns due to the uncertainty in establishing failure criteria from detected flaws is great. A fundamental study that establishes the basis for crack initiation and propagation would provide valuable insight to the understanding of empirically based criteria. RP614, a fundamental study of crack initiation and propagation, with Lawrence Livermore Laboratory and Science Applications, Inc., will establish basic predictive capability requirements for assessing potential failure from detected flaws. Success in this and related projects will permit calibration of simplified design methods in fracture problems.

A combined calculative and experimental approach will be used to predict crack initiation and propagation. This project will calibrate sophisticated finite-difference computer programs with accumulative damage failure models by simulating failure in controlled test specimens.

A fracture mechanics methodology that can be applied in the plastic regime is required to permit a quantitative assessment of the margins of design inherent in nuclear reactor pressure vessels. While traditional linear-elastic fracture mechanics procedures are adequate for analysis of some plant conditions, their direct application to fully plastic materials behavior is questionable. Development of a methodology for plastic fracture will permit the assessment of design safety margins without unrealistically conservative boundary conditions, as is the case when traditional linear elastic fracture mechanics procedures are applied.

To fill this need, General Electric Co. and Battelle, Columbus Laboratories are working to develop the methodology required to make sound engineering predictions of the behavior of flawed structures in the plastic regime (RP601). The following elements are included in the project:

- Developing the theoretical methodology necessary to fully describe plastic behavior of flawed structures (i.e., upper-shelf behavior)
- Developing the capability to apply the theoretical plastic fracture methodology to the analysis of a flawed engineering structure. A proper analysis should be capable of providing stresses and strains for both the initiation of crack growth and failure instability.
- Determining appropriate materials properties, as required, to support and successfully apply the above analysis
- Designing and conducting definitive engineering tests to establish benchmarks in the development of analytic procedures and to ensure the adequacy of such procedures

Analytic procedures

This effort is directed to the application of state-of-the-art analytic techniques to the solution of present engineering problems. It does not consider the development of new analytic techniques, specifically in the area of computer code development.

The projects focus on those near-term engineering problems whose solutions are possible by careful application and/or slight extension of established techniques. An example of a problem of this type is the application of elastic-plastic fracture mechanics to determine the margin of safety for a circumferential flaw in a pressurized pipe. The solution of this problem does not exist in the literature, yet it can be analyzed by the application of well-established principles.

Recently, a number of BWRs were shut down for repair of cracked piping in 4-inch recirculation bypass lines. These cracks were circumferential and located near the heat-affected zone of the piping welds. RP585 with Battelle-Columbus is in the final stages of study and has already demonstrated—in a manner consistent with Section XI of the ASME Code—that the critical flaw size for unstable fracture of cracks of circumferential orientation is such that leaking will occur long before the crack reaches the size necessary for full-scale pipe rupture.

This most important finding confirms the viewpoint that leak detection is an adequate and safe method of discovering such cracking long before an unsafe condition develops.

Another recent project, RP498 with Teledyne Materials Research, has studied the analytic aspects of the BWR feedwater nozzle cracking problem.

A three-dimensional finite element method fracture mechanics analysis has been performed for the Millstone 1 feedwater nozzle to determine critical flaw size, as required by the ASME Code, Section XI. Improved sophistication of this analysis over previous efforts has resulted in better definition of critical flaw size for specific flaw sizes, shapes, and orientations of practical interest. Results from study of the specific Millstone 1 configuration will provide guidance in evaluating a generic problem in BWR feedwater nozzles and other similar nozzles. *Program Manager: Karl Stahlkopf*

LWR BLOWDOWN HEAT TRANSFER

For the past several years, EPRI has funded research in LWR blowdown heat transfer—an area of investigation of core heat transfer performance under hypothetical LOCA conditions. Both BWR and PWR system responses to the prescribed design basis accident—the guillotine cold leg break with discharge from both ends of the broken pipe—have been investigated in four different projects, now in various stages of completion.

The BWR blowdown heat transfer project, sponsored with General Electric and NRC, was recently completed by GE (RP288). It was carried out in a scaled test apparatus to study the system performance and thermal response characteristics of BWRs under LOCA conditions. Specific project objectives were: to measure the time from LOCA initiation to occurrence of critical heat flux (CHF); to evaluate effects of lower-plenum flashing and to improve the understanding of post-CHF and lower-plenum flashing heat transfer to evaluate bundle thermal behavior prior to the availability of emergency core cooling. The results of the project may be summarized as follows:

- The maximum measured cladding temperature was less than 1400°F for the *peak power* bundle test, despite the fact that the test apparatus, by atypically rapid initial core flow coastdown, forced CHF at about 1–2 seconds. Maximum temperature for the *average power* tests was typically less than 900°F. (The NRC final ECCS acceptance criteria, of course, require a showing that under LOCA conditions this value will

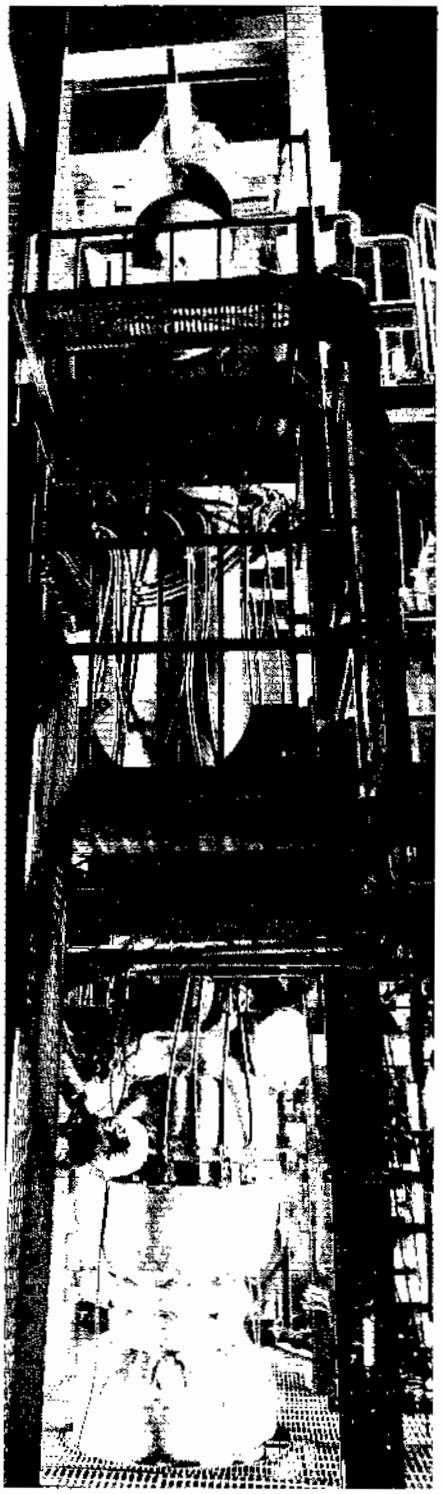


Figure 1 The two-loop test apparatus used for the BWR blowdown heat transfer project was built for RP288 at General Electric's nuclear center in San Jose, California. The apparatus was started up early in 1974 and the project was completed recently.

not reach 2200°F, which has been designated as a conservatively safe level.)

□ A number of inherent cooling mechanisms were demonstrated for which no credit is currently taken in making the calculations to satisfy the acceptance criteria, such as bundle cooling by residual fluid in the bundle; steam updraft cooling above the mixture level in the bundle; cladding rewetting during lower-plenum flashing; and cladding rewetting in the period after lower-plenum flashing due to fallback of fluid from the upper plenum.

A study of independent parameter variations showed that the area of the break cross section and initial fluid mass had a significant effect on the system thermal-hydraulic blowdown response. These parameters affect the timing of key events during blowdown and hence the bundle heatup response. Parameters that had either much smaller or no discernible effects over the range investigated were alternate power decay, bundle bypass orificing, initial fluid subcooling, and alternate lower-plenum geometry.

The system response was also observed to be insensitive to large variations in the bundle power (3–6.5 MW). This observation supports the approach used in current BWR LOCA evaluation methods—obtaining the nominal core inlet conditions for the bundle heat-up calculations from thermal-hydraulic blowdown calculations, using the core average power.

Bundle heat transfer can generally be characterized as nucleate boiling beneath the two-phase mixture level, with steam cooling above the mixture level. In the case of the peak power bundle, the post-CHF heat transfer mode can be characterized as transition boiling to film boiling; after uncovering of the top of the bundle, the heat transfer mode was steam cooling.

CHF generally occurs on fuel rods after the lower-plenum flashing surge due to depletion of the two-phase mixture level. However, in the peak power bundle tests, CHF occurred early, due to the critical power being exceeded during the nontypical test core flow coastdown while the fluid mixture remained above the bundle. When applied to the test apparatus, the current BWR LOCA evaluation methods show a substantial margin in the prediction of system blowdown performance and in the prediction of peak cladding temperature.

RP289 with Combustion Engineering, Inc., the PWR blowdown heat transfer project, was jointly funded by EPRI and C–E. A large number of rod bundle blowdown tests under average bundle power conditions have been performed. The results of these tests indicate a time-to-CHF ranging from 0.9 to 1.9 seconds for the tested conditions. Evidence available indicates that CHF results from the rapid increase in test section fluid quality and propagates rapidly throughout the entire test section length as the fluid is expelled from both ends. Further analysis and evaluation of the test results are under way. Computer modeling of the test section, using measured bundle transient fluid boundary conditions, will be performed to evaluate local conditions within the rod bundle.

A study of CHF in flow reversal transients at Massachusetts Institute of Technology is nearing completion (RP292). Such transients are of particular interest because in passing through zero flow, the channel experiences conditions that are difficult to represent in steady-state experiments, and flow reversals in a heated channel can lead to an enthalpy maximum in the interior of the channel. This can lead to fluid expulsion on inception of net vapor generation.

Based on the experiments and analyses, the following major conclusions have been drawn:

□ In flow reversal transients, CHF can be predicted by using steady-state CHF correlations. It had been established earlier that accurate prediction of CHF in other constant pressure flow transients can be obtained by use of steady-state CHF correlations in conjunction with calculated instantaneous local conditions during the transient. Results from this study support extending the validity of this conclusion to transients involving flow reversals and stagnation.

□ A useful simplification of the physical mechanism of CHF is that CHF can occur in a flow channel due either to excessive wall heat flux or to excessive vapor flow rate through the channel. Due to vapor flow, either of these conditions can suspend liquid away from the wall. An empirical correlation of data shows that for a given pressure and geometry the limiting heat flux and vapor flow values remain fairly constant over a wide range of total mass flux through the channel.

□ At low flows and at low void fractions, the heat-flux-limited (pool boiling CHF) mechanism governs, and the allowable heat flux under these conditions is greater than the operating reactor heat flux levels. CHF did not occur on the first reduction-to-zero flow in the experiments, nor is it likely to occur under similar flow conditions in a PWR large cold leg LOCA.

□ A qualitative theory of low-flow CHF provides a logical merger of CHF prediction schemes for steady upflow, countercurrent flow, and downflow.

Based on the tendency in flow reversal transients toward fluid expulsion, it is hypothesized that the worst PWR LOCA break location from the standpoint of time-to-CHF is one that produces a flow stagnation in the core. For such a case, a simple analysis shows that even if CHF were delayed, the unchecked energy deposition into the coolant would cause 100% voiding in 1–2 seconds.

In a jointly funded project with Westinghouse Electric Corp. (RP494), PWR single- and multiparameter blowdown heat transfer tests are being performed. To date, only a few tests have been completed. All tests were conducted with flow down through the 49-rod test section. The bundle power was skewed to the bottom.

The preliminary results indicate that for downflow conditions, CHF occurred—as predicted—first in the central high-power zone and then in the peripheral low-power zone. In addition, CHF generally occurred along the lowest 20% of the actual length of the bundle.

More conclusive data on LWR core heat transfer performance under LOCA conditions are expected to be available as soon as all the projects have been completed.
Project Manager: Kjell Nilsson

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

INTEGRATED ASSESSMENT

The integrated assessment subprogram of the Environmental Assessment Department aims at developing comprehensive estimates of the environmental impacts associated with alternative technologies or siting options. So far, most of the work has concentrated on the various environmental impacts associated with coal technologies.

In a project on monetary estimates of air pollution damage from coal-burning power plants (RP755), an urban area and a rural area with several coal-burning power plants are under study. The environmental impacts on human health, animals, agriculture, and materials are being estimated and quantified. The monetary estimates will facilitate cost-benefit analyses of alternative emissions control procedures for the study regions. The uncertainty over the existence and extent of the impacts will be reflected by range estimates.

This subprogram is concerned also with the less tangible environmental impacts associated with power generation, which include landscape alteration and changes in visibility and noise levels. Major projects have been halted by relatively small groups arguing on the basis of their offended sensibilities. Confrontation of this kind can be very difficult to deal with. The question of whether or not the intangible impact, which is the cause of apprehension, has been weighted in the decision process is not always well answered. In an effort to learn the importance and weight of intangible environmental impacts, EPRI recently sponsored a workshop to consider various ways to articulate and quantify them.

In addition, EPRI is supporting work with another contractor under RP755 to adapt and apply two methodological approaches to quantify the relative impact of visibility reduction in the western states. This work is expected to produce a methodology to derive monetary estimates of the importance of good visibility.

EPRI is also concerned with the socioeconomic effects associated with energy development. These may be particularly acute in the sparsely populated areas where many energy resources are expected to be developed. A planning study on the socioeconomic impact of power generation (RP936) is under way to determine research needs and to suggest areas where EPRI might support future work.

Another planning study will begin shortly on supply of fuels as influenced by transportation (RP952) and will examine existing knowledge and the need for further work on environmental impacts associated with fuel transport. Future energy supply scenarios depend on extensive fuel transport, and environmental constraints related to this transport need to be foreseen and understood.

Other areas to be explored in 1977 include: a comparison of the environmental impacts of alternative cooling technologies; a comparison of the environmental impact of a large power plant compared with several smaller plants that are geographically separated; a study of the impact of alternative nonsignificant deterioration scenarios; and environmental baseline studies in association with a major fossil fuel development project (to be selected). The integrated assessment subprogram will also begin work on the societal and environmental impacts of energy shortages. *Project Manager: Ronald Wyzga*

TIME-OF-DAY AND SEASONAL ELECTRICITY LOADS

This subprogram was initiated with the workshop "Development of Methodologies for Forecasting Time-of-Day and Seasonal Electricity Loads" in December 1975 at Pacific Grove, California (EPRI SR-31). The papers and discussion contributed by the workshop participants were instrumental in planning the research.

The time-of-day and seasonal subprogram is pursuing two independent but related approaches to developing long-term load forecasting methods and models for electricity demand. These can be characterized as the macro and micro approaches. The former deals with the aggregate load duration curve for representative utilities in arbitrarily defined regions of the country. The problem is to relate statistically the aggregate load duration curves to other aggregate variables that are descriptive of regions and their electricity customers. The latter approach deals with modeling the load pattern of individual electricity customers. The customers' load pattern is statistically related to their stock of electric appliances and other variables that describe how and when these are operated.

In the macro approach, a project (RP1008) authorized at the November Board of Directors meeting calls for the building of a regional load curve model, which will relate the load to the composition of energy use by the Standard Industrial Classification (SIC) code, (i.e., commercial and industrial, residential, public, and other uses). Also included in the model will be relevant variables, such as regional economy, weather, growth history, and degree of urbanization. This aggregate model will be used to interface the aggregate energy utilization forecasting models being developed in the Demand Program and the electric utility model being developed by the Supply Program. It will also provide a benchmark against which we can compare the results obtained by reaggregating micro load forecasting models. The aggregate load forecasting model will be useful for ascertaining the implications of the different growth rates of U.S. manufacturing and service industries as well as for studying the implications of interregional migration of households and industries.

In the micro approach, there are several projects in progress that are developing methodology for long-term forecasting of residential electricity loads by time-of-day.

The purpose is to obtain a characterization of residential load patterns that is conditional on household electric appliances, family composition, employment status of the adults, family income, weather, and the time-of-day price of electric power. The models will be useful for the analysis of three problems in load forecasting. First, long-term changes in the level and distribution of economic and demographic variables may markedly alter the present load pattern and generation requirements. Second, accurate long-term forecasting of load pattern and conservation analysis require the incorporation of the effects of changes in the composition and energy efficiency of the electric appliances. Finally, quantitative measurement of the effects of varying time-of-day prices on the load pattern is necessary for determining the efficiency and benefits of peak load pricing as a load management tool.

The micro load curve models will reflect the potential contribution of each major electric appliance to the time-of-day load pattern. In turn, the time-of-day use of the appliances will be related to the weather, the socioeconomic characteristics of the households, and the price of electricity. These micro models will be useful for evaluating the long-term implications of demographic changes and economic growth on residential load patterns. The models will also be used to evaluate the responsiveness of the individual load curves to time-of-day pricing and other rate structures.

The methodology studies being developed use data on approximately 400 residential customers of the Connecticut Light and Power Company, a subsidiary of Northeast Utilities. The data were collected in a residential time-of-day rate experiment sponsored by the Federal Energy Administration, among others. A preview of the results of these forecasting methodology studies will be presented and discussed at the second workshop on the development of methodologies for forecasting time-of-day and seasonal electricity loads to be held at the Aspen Institute in Colorado, March 30—April 1. The workshop will also consider a number of other papers contributed by researchers throughout the country who are studying the problems relevant to long-term load forecasting. The workshop proceedings will be published as an EPRI special report.

Micro-level work on the load pattern of commercial establishments and industrial users will be initiated this year. In developing load curve models, micro work on residential users relies primarily on statistical inference. In the industrial area, however, it is probable that considerably more reliance will be placed on engineering information in the form of process models. These in turn can be used to predict both the time-of-day load pattern of the industry and the effect that changes in employment, technology, time-of-day pricing, or industrial activity have on the load pattern.

Ultimately, the micro-level studies of load pattern will be reaggregated to replace the much simpler and less structurally detailed macro load curve model. It will, however, be several years before such sophisticated and detailed models of the load pattern are completed for all uses. Meanwhile, the model of the aggregate regional load curve will remain a keystone in the Energy Analysis and Environment Division's aggregate forecasting models for U.S. energy requirements.

In addition to the projects on load forecasting, there are several technical performance measurement and evaluation studies that will yield information on the load requirements for new electricity-using technologies. These projects include a study of the implications of the electric automobile for utility system loads (RP758) and analyses of residential space conditioning systems, emphasizing heat pumps (RP137 and RP432). *Project Manager: Anthony Lawrence*

ENERGY MODELING

A recent survey of energy modeling efforts identifies four types of models: (1) sectoral models, covering the supply or demand for specific fuels or energy forms; (2) industrial market models, which include both supply and demand relationships for individual or related fuels; (3) energy system models, which encompass supply and demand relationships for all energy sources; and (4) energy-economic models, which model the relationships between the energy system and the overall economy. In the last few years, increasing emphasis has been placed on the fourth category. In past modeling efforts the feedback between energy systems and the economy was largely ignored. The energy-economic model has grown out of the recognition that the cost and availability of raw materials may have significant near- and long-term implications for the economy.

One of the most ambitious attempts at energy-economic modeling is being carried out at Stanford University. The PILOT model (RP652), under development at Stanford's Systems Optimization Laboratory, includes a description in physical terms of industrial processes and the demands for energy consumption, added capacity, government services, and net exports. Raw energy extraction and energy conversion processes, as well as energy imports and exports, are described in a detailed energy submodel.

Four linkages connect the energy sector to the rest of the economy: energy demands of the economy; materials needed for energy processing and capacity expansion; total manpower available to all sectors (including energy); and a balance-of-trade constraint that requires equating total exports to total imports over each five-year period.

The model is designed to assess U.S. energy and economic options in terms of their effect on the standard of living with the aim of helping to develop policies that are resilient to various contingencies. Specifically, PILOT will be used to provide analysis and information on such questions as:

- Are we consuming domestic energy resources too quickly?
- Are we making sufficient investment now so that new energy technologies can come into commercial operation if needed in the future?
- Will we have sufficient physical capacity to build new plants and equipment in the energy and nonenergy sectors so that the growth in consumer consumption will not be seriously hampered?
- What are the various energy options under different patterns of crude oil import prices?
- What will be the short- and long-term impacts if oil and gas discoveries in the U.S. are fewer and/or less productive than predicted?
- Can we develop a robust U.S. energy policy—one that allows for various contingencies?

Data collection, aggregation, and model development began in 1975. An 8-period version of the model was recently completed and is now being used to explore the impact of various energy policy decisions on the U.S. economy. *Project Manager: Richard Richels*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

INSTRUMENTATION AND CONTROL SYSTEM RESEARCH

The key to successful power system control is the effective use of reliable instruments and protective relaying systems by experienced operators. Although the existing equipment is serving the utilities well, tomorrow's systems will require greater sophistication of the control system, improved accuracy, better reliability, and the usual economy. To accomplish this, better measuring and sensing techniques will have to be developed, signal transmission improved, and new processing technologies exploited. However, the new improved protective relays and control systems will have to be integrated with the existing systems.

There is ample reason for concern over our ability to manage the concentrated high-capacity systems of the future. A conservative estimate of growth in electric power use shows that the power production target for the year 2000 should be at least 7500 billion kWh, almost four times the present level. Advanced UHV overhead transmission lines of the future can be expected to carry three to six times the power per mile of their lower-voltage predecessors. Newly installed underground transmission lines promise a doubling of underground power transfer capacity by 1985. Dc transmission systems will soon augment the ac systems, and compact, gas-insulated substations will further concentrate future power transfers. Finally, the introduction of fault current limiters and similar devices calls for a restructuring of control and relay systems.

Substations will shoulder the load

The burden of monitoring and control is centered at the gateway of all power transfer: the HV substation as illustrated in Figure 1. This is where all readings are recorded and interpreted and action is taken.

We are fortunate that today we have the advanced electronics technology to help us handle the burgeoning power flows through bulk power substations. Of particular interest are the minicomputers and their subset, the microprocessors.

Computers are accepted components for power system dispatching and if their cost continues downward, will become the cornerstone for substation control and protection. The computers, coupled with inexpensive optical communication links, multiplexers, and a few special electronic subsystems, now appear to be natural components for the new substation integrated control systems. This is the premise for the EPRI R&D projects described here for instrumentation and control.

Electrical sensing elements

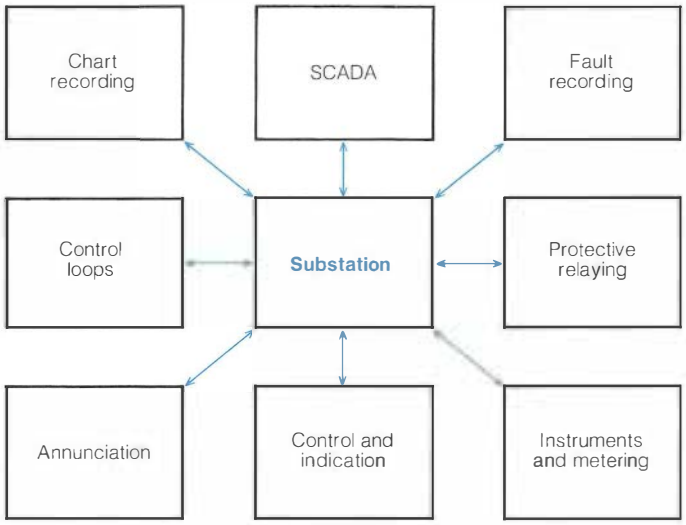
Our ability to measure voltage and current is fundamental to the control of power systems. From these, other quantities such as real and reactive power, total energy, line impedances, and so on are derived. The sensing elements must support data acquisition systems, which require information with a frequency ranging from once an hour to once every 100 microseconds or less. The data must be accurate to within a fraction of a percent for revenue-metering purposes; it must also be reliable for support of protective relaying functions.

The measuring equipment must survive in the harsh environment of temperature, mechanical stresses, and electromagnetic interference normally found in bulk power substations. The modern current transformers (CTs) and potential transformers (PTs) are remarkably good devices, meeting the requirements listed above very well. However, for UHV application their cost is very high. The fidelity of the output signals from the CTs and PTs is also in doubt in the high-frequency region, which is of interest for high-speed relaying. Further, the cables leading from the transformers to the control houses now pick up high-frequency noise, interfering with operation of relay and control equipment. Saturation of transformer cores also poses problems for the user.

In recognition of all of these problems, as well as the trend toward digital control systems in substations, EPRI is sponsoring a development project for a digital EHV current transducer (RP560). When using digital systems for control of a process that is basically analog, it is recognized that the digitized signals should be produced as close to the analog sensor as possible. Once the information is digitized, there will be few significant errors introduced in the processing of the data. Further, the security provided by encoding is vastly improved over conventional analog systems. The transducer developed by Westinghouse Electric Corp., therefore, has an analog-to-digital converter in the measuring head immediately after the primary current transformer at line potential. Low-loss, single-fiber optical waveguides are used to bring the information from the measuring head through the inside of a simple, hollow support porcelain and through cable conduits to the control room; the control room may be as far as 300 meters (1000 feet) from the transducer itself. A fast-starting power supply that takes energy from the line itself through a small auxiliary current transformer has been developed to support the conversion and transmission equipment in the measuring head of the transducer.

A similar development effort is being conducted by General Electric Co. under EPRI sponsorship (RP668); its objective is to develop a current transducer with metering accuracy for HVDC lines. This transducer utilizes a low-impedance shunt instead of the CT used in the ac transducer. It will require power supply from ground since no dependable device to siphon power directly from the high-voltage circuit for the transmitter has been found. The best choice now appears to be a small, high-frequency, cascade transformer arrangement.

Figure 1 The conventional control and monitoring of a substation is now handled by a multitude of separate instrumentation systems.



It is recognized that the current transducers described above are adaptable to voltage measurements if coupled with a stable voltage divider. However, voltage-measuring equipment is also getting attention in two other projects.

One project nearing completion (RP134) is the development of calibration equipment for coupling capacitor voltage transformers (CCVTs) used for metering high-voltage lines (*1, 2*). The work completed to date by the National Bureau of Standards has verified the need for periodic calibration of CCVTs, and NBS has produced a calibration system with about 0.05% accuracy. Experience gained from using the equipment should provide guidelines on how often the calibrations of metering-class transducers should be performed.

The other project, the HVDC prototype link (RP213) under contract with General Electric, will result in a compact, gas-insulated potential transducer suitable for a gas-insulated HVDC terminal (*3*).

Signal transmission

Control circuits in high-voltage substations are plagued by a high level of electromagnetic interference (EMI). The new single-fiber, low-loss, optical waveguide appears to solve all these problems at a cost that is expected to be competitive with existing cables in a few years.

Optical fibers no doubt have several other advantages over cables. They cannot start an electrical fire, and the fibers do not need physical separation from each other since interference between fibers is negligible. This allows the use of very simple, inexpensive ducts for the fiber cables instead of the relatively expensive conduit systems used in today's substations. On the negative side is the fact that the fibers are relatively fragile, but this should not be a problem if the fiber cables are simply rolled out in shallow surface ducts.

The optical communication systems, coupled with transducers like those described above, or relatively simple multiplexers placed strategically in switchyards, could revolutionize the design of instrumentation and control systems in substations, as well as in power plants in general. The potential cost-benefit of these new systems could be substantial, which justifies continued evaluation and development by the utility industry.

Protective relaying and high-speed control

EPRI is in the process of developing high-speed fault current limiters. One utility is independently pursuing an ultrahigh-speed relay. Such devices as these need elements capable of detecting faults in a small fraction of a cycle. However, the ability to distinguish faults from switching surges in the same time frame is missing. For example, the noise spectrum to which the devices will be exposed is not known. EPRI is therefore sponsoring a project with the objective of gathering, analyzing, and classifying transients on transmission lines in the 2 Hz to 100 kHz frequency range. The instrumentation system needed for this is being developed by Westinghouse (RP751). High-frequency current and potential transducers will be built and integrated with a high-frequency digitizer and data storage system. The project should provide data that will also be useful to substation equipment designers and to systems analysts for high-frequency transient analysis programs.

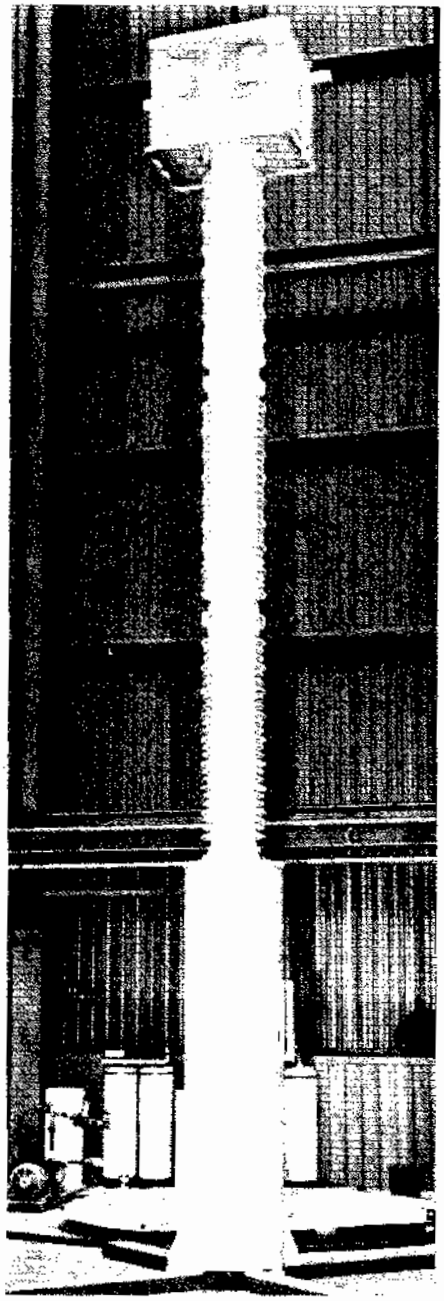
Direction of future research

The data received from the sensing elements must be processed in a variety of ways. It is therefore natural to assess the potential of minicomputers or microprocessors as a means of processing the data acquired by digital transducers. Many different system solutions are possible when using computers that are combined directly with communication links. However, we feel that a distributed processing-type system is needed because protective functions would need dedicated processors. Hence, ties to high-level processors would probably be used only for the logging of relay operations and the monitoring and supervision of the relay performance.

Computer-based relays can be built with a self-checking feature and possibly also with limited error-correcting functions. This could eliminate the need for preventive maintenance of the relays and allow utilities to repair relays on a correcting-maintenance basis only, thereby reducing the maintenance costs considerably, while increasing the dependability of the protection substantially.

The substation having a distributed processing system within itself, in turn, may act as the hub in a wheel with the spokes tied to data acquisition systems in the underlying distribution substations. The master processor in the substation may, in turn, act as a preprocessor to the central dispatch and supervisory control systems now well established in most utilities. Some progress

Figure 2 A 500-kV electronic, digital current transducer prototype shortly before verification tests in the manufacturer's laboratory.



along these lines has been made, with the so-called substation integrated control systems emerging from different utility-sponsored development projects.

EPRI is now sponsoring one project (RP213-3, under contract with The Boeing Co.) that will advance the state of the art in high-speed, real-time data acquisition systems (specifically, fault data), which require relatively high bandwidth for proper operation. This type of system is intended for use in the HVDC prototype link (*3*). The objective is to develop hardware and processing methods for transmitting up to 16 recording channels of fault data over a voice-grade communication channel with a reasonable throughput time. This will no doubt require the use of data compression techniques. If successful, it will be possible for a systems or protection engineer to receive direct information from fault recorders in various substations within a few minutes after a disturbance. It might then be possible to analyze the faults and quickly determine what corrective action might be required. The proposed system would also acquire event data to supplement the fault records and provide the normal operating logs, which can be used for future system planning. The system will also be capable of incorporating control functions, but none are anticipated to be implemented at this time.

Future work will no doubt also be needed to develop prototype relays for high-impedance faults and relays coordinated with fault current limiters. The favorable cost trade-off between control systems and main circuit equipment will also be pursued whenever a small investment in control equipment can offset large investments in power equipment. *Project Manager: Stig Nilsson*

References

1. Transmission and Distribution Division Report. *EPRI Journal* No. 1 (February 1976), p. 41.

2. Project Highlights. *EPRI Journal* No. 4 (May 1976), p. 42.

3. "Compacting DC Terminals." *EPRI Journal* No. 10 (December 1976), p. 18.

CLARIFICATION

The December Electrical Systems Division R&D Status Report (p. 41) mentioned a completed project involving a current-limiting conductor (CLC) developed by Phoenix Electric Corp. (RP324) and publication of the final report (EL-286). It should be pointed out that the CLC developed and tested on that project would undoubtedly be too large and expensive for application on a utility system. It was shown analytically by the contractor that the inclusion of a switched resistor held promise of the 90% cost reduction cited. The switched resistor unit was not tested because such testing was not within the scope of the project.

The concept of a switched resistor, fault current limiter has been under development with I-T-E since 1974 (RP281), and a prototype is expected to be completed during 1978.

Under New Publications in the same issue (p. 59), a summary was given of a final report (TD-136) on reduction of ac losses in high-temperature superconductors. Although the contractor, University of Southern California, was asked to make ac loss measurements on Nb_3Ge samples as well as to reduce the losses by treatment of the sample surfaces, no reduction of losses was achieved.

A second final report (7813-1) on cryocable terminations expressed considerable confidence in vacuum-insulated, LN_2-cooled cryocable. However, the reader should be cautioned that vacuum insulation may be neither feasible nor economical as a thermal/electrical insulant for cryogenic cables of reasonable length.

ATWS—Impact of a Nonproblem

by Gerald Lellouche

It is to be hoped that by the time this article appears in print, the ATWS controversy will have been resolved. It is doubtful, however, that a problem (or as we shall show, a nonproblem) already eight years in the making will resolve itself so quickly. ▫ An EPRI technical article

ATWS is an initialism for anticipated transient without scram. In Nuclear Regulatory Commissionese it refers to a scenario in which an anticipated incident causes the reactor to undergo a transient. Such a transient would require the reactor protection system (RPS) to initiate a scram (rapid insertion) of the control rods to shut down the reactor, but for some reason the scram does not occur. The transient proceeds to a natural termination; potentially, the core is damaged and radiation may be released onto and beyond the plant site, resulting in property damage and personal injuries.

Several questions arise that affect this scenario. Scenarios are useful tools. They are used effectively by writers of fiction, the media, and others to guide the thinking process. Before passing from the scenario to reality, however, the question of how likely it is must be answered. Before insisting that plant design must be altered to effectively eliminate the problems in the scenario, questions concerning cost-benefit–risk reduction should be raised.

Dollar cost already in millions

Although the ATWS question has been with us with increasing impact since the late 1960s and in terms of manpower and computer time has probably exceeded a cost of $10–$20 million, an accepted answer to whether ATWS is real enough to require regulation has not yet been reached. In the important 1973 regulatory document WASH-1270, "Technical Report on Anticipated Transients Without Scram for Water-Cooled Power Reactors," the AEC attempted to deal with the question of "how likely" as well as most other aspects of the ATWS. In many ways, the effort was less than successful.

WASH-1270 was particularly important in that it seemed to try to use rational methods (probabilistic/statistical) to determine whether an accident scenario was indeed worth regulating.

Unfortunately, WASH-1270 was a mixed bag. It applied elementary statistics to a situation that required a much higher degree of mathematical sophistication. It did not consider all the extant information and so ended with an incomplete data base. It concluded that the likelihood of the RPS failing to respond to a demand was less than 16 in 100,000 (1.6×10^{-4} per demand) with 95% statistical confidence (S-confidence) (*1*). It "picked" a value of 1/yr as the frequency of incidents that would lead to transients requiring scram, although it also stated that the actual frequency was more likely to be between 0.1/yr and 0.5/yr.

WASH-1270 identified a number of anticipated transient initiators that would strongly challenge the integrity of the system (if the RPS failed to act), but did not address the question whether any of them would indeed lead to consequences that would violate any of the out-of-plant radiation limits, such as 10CFR-100. It concluded that it was desirable that the probability for ATWS violating 10CFR-100 be less than about 1 in 10 million/yr (10^{-7}/yr). It also concluded that the total probability for all accidents (including ATWS) violating 10CFR-100 should be less than about 1 in 1 million/yr (10^{-6}/yr). But, it did not supply a basis for the choice of these numbers.

Since WASH-1270, these numbers (10^{-7}/yr for ATWS and 10^{-6}/yr for all accidents) have been repeatedly introduced by members of the NRC staff in NRC meetings, at the Advisory Committee on Reactor Safeguards, and in testimony at various hearings of the Atomic Safety and Licensing Board. The numbers have gradually achieved a stature that is largely undeserved because they bear no clear relationship to any underlying reality. We shall show, however, that reactors already have achieved most of this stringent requirement by considering a document that did not exist when NRC was writing WASH-1270. This newer document is WASH-1400, the reactor safety study.

The process by which the NRC staff identified serious potential transients was to require each of the vendors to perform various accident analyses. After reviewing these analyses of postulated ATWS events, the staff concluded that several anticipated transients in boiling water reactors would require prompt action to shut down the reactor in

Gerald Lellouche is Program Manager of Statistical and Environmental Analysis in the Nuclear Power Division, EPRI.

order to avoid serious plant damage and possible off-site effects. In PWRs, several anticipated transients would require rapid shutdown of the reactor to avoid pressure surges in the primary system that in some cases might exceed allowable limits.

The NRC staff found that the great majority of postulated ATWS events did not lead to serious consequences, but that design changes to improve protection against ATWS would be appropriate in anticipation of the large numbers of plants expected in the future. The point of importance here is twofold:

- No transient has been identified where the calculated off-site effects would exceed 10CFR-100.
- Most anticipated transients have no serious consequence.

Much time has passed since WASH-1270. Since 1974 the reactor vendors have been preparing increasingly sophisticated analyses of their particular systems. They have identified design changes that could lead to greatly increased RPS reliability; but NRC, while encouraging such endeavors, has failed to agree that any such changes would alter any of the values appearing in the now three-year-old WASH-1270. During this period the vendors have also identified system modifications that would tend to mitigate the consequences of an ATWS to the point where nothing significant would occur. The cost of making such changes was, however, not publicly addressed. Finally, in December 1975, the AEC regulatory staff issued a series, "Status Reports on ATWS," one report for each vendor. These reports identified a large number of significant differences between the NRC staff and each vendor. All these differences are based on the scenario method and have little to do with answering the question, How likely? Therefore, on the question of which values of lifetime varying parameters should be used, NRC requires that a value should be the worst during 99% of the cycle. A statistically valid procedure would be to repeat the analysis as a function of the variables and then average over the cycle. Thus, NRC requires that the initial conditions should be essentially at their worst (e.g., for PWRs the ATWS should be assumed to occur during a boron dilution procedure). Again, a statistically valid procedure would be to consider all the likely initial conditions, weight them with their expected time intervals, and average them. Thus, in performing the analysis, it must now be assumed that not only must the RPS fail, but other mitigating systems as well: that one relief valve does not open, and one of those that does open, does not close.

Is ATWS real?

How rational is any of this? Is ATWS real enough to warrant so much time and effort?

In October 1975 EPRI undertook the task of reappraising the entire rationale for making ATWS important enough to require regulation. The basic conclusions of the group doing the reappraisal can be stated to be that ATWS does not require regulation, with the possible exception of requiring an overpressure recirculation pump trip on BWRs. In December 1976 EPRI published the first two parts of this study: a definitive analysis of WASH-1270 (NP251) and an evaluation of societal risks due to RPS failure (NP265). Two other parts of this study will be published later.

Reality shows us that the world is less than perfect and that we cannot control, with perfect reliability, all things all the time. (A. Lincoln put it a little differently.) This implies that during the life of any power plant, events that are undesired from an operational viewpoint can be expected to occur with greater or lesser frequency. Statistically, we can be quite reasonably sure that some will occur on an average of once a year, while others may be as rare as only once in 30–40 years. The total number of such events in BWRs, for example, can be shown to depend on how old the plant is (Figure 1) and will vary (again an average) from about 23/yr the first year to about 2/yr after five years of operation.

Some of these events will lead to transients that will not require the intervention of the RPS. Others would call for the RPS to shut down the system, but if no scram occurred, nothing of a serious nature would result. Finally, some few events may call for a scram that if greatly delayed, would result in damage to the core and potential radiation release to the off-site ecology.

What is the frequency of incidents?

The first question is, What is the frequency of those anticipated events that would require scram to prevent core damage (anticipated events of consequence)? The total expected number of events per year that would require scram is precisely found from the data for BWRs in Figure 1. Thus, after about five years of operation we expect the upper limit to the frequency per year of all events to be about 2 for BWRs. Due to the difficulty of collecting the necessary data, a more complete discrimination of this frequency is not complete at this time. For the purposes of this article, the number of incidents leading to transients of potential signif-

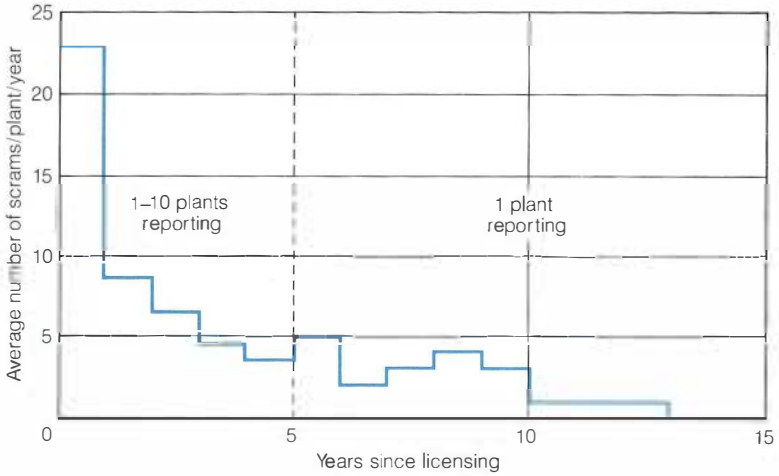


Figure 1 The learning curve with an average BWR shows sharp dependence on the length of time the plant has been in service; the number of scrams per year decreases with unit maturity.

icance is assumed as this total number of scram initiators, a clear upper bound.

Given that in the long run one can expect one or two events a year that call for a scram, even though most of them will not cause problems if the scram did not occur, the second question of importance is, What is the probability that the RPS will fail to operate correctly?

This question is more difficult to answer because so few events have occurred and because of the difficulty in correctly treating the data. This latter point is important because we wish a realistic evaluation of the probabilistics, not one that is merely conservative. Two cases where the RPS was inoperative have been documented. The first occurred in 1963 in the Kahl reactor in Germany; the second, in 1970 in the N-reactor at Hanford. The N-reactor instance is usually disregarded because the N-reactor does not resemble any commercial power reactor. In the Kahl instance (a U.S.-designed 15-MWe BWR that became operational in 1960), it was discovered on test that a scram signal would not have been initiated if required because of a common-mode failure (CMF) in the scram relays.

The N-reactor instance should not be included in the data because of the extreme design disparity between the N-reactor (a graphite-moderated, cartridge configuration fueled dual purpose unit) and any commercial LWR. The German BWR instance likewise should not be included because of the concept of rectifiability. That is, any CMF that is discovered is not expected to occur again (certainly not with the same frequency) since redesign, test and maintenance, and/or other quality assurance methods will be adjusted to eliminate that particular failure mode. Thus rectification eliminates potential failure modes and produces a better-than-original condition.

If the purpose is to secure a realistic view of system failure, one must be very careful in defining a CMF. Of interest is the class of initiators that will lead to a failure of all or nearly all the control rods in the RPS in such a way that the scram activation mechanism appears to fail in a time interval that on average is less than half of the test interval. There are conditions that will affect the entire RPS, but because of time considerations, they are not credible as CMF initiators in that they are observable before failure.

To this class belongs the thermal stress initiator, which leads to collet cracking. The time period for actual failure of a single collet is greater than one year for this mode, and in fact no drive failure by collet cracking has been observed. A second class of CMF initiators that statistically should not be included in ATWS probabilistics are those which would be discovered during startup testing or earlier. Thus, the initial inability of any single rod or bank to scram would be discovered during the hot zero- and low-power testing that is required of each reactor.

One is left then with a reduced class of potential CMF initiators that either take a number of months of actual reactor operation to develop (longer than the startup period) or, because of maintenance or RPS modification subsequent to startup, are externally introduced. In this latter class is the only known case of inability to scram in a commercial power reactor (the Kahl instance), where the replacement for a set of contacts (2) was faulty and they stuck closed. Quality assurance (QA) modifications were made in LWRs so that such incidents would not go undiscovered again.

Note that we do not have to assume that such a fault will not occur to remove it from the class of credible CMF initiators, but only that it will be discovered by special testing as it occurs. Thus, the fact that 4 of about 200 contacts were discovered to be faulted several years later during startup testing of another reactor does not imply the failure of QA administrative methods (3). It actually validates them (in that particular case) because the special testing of the new system did in fact bring the failures to light. Thus, rectification is a valid concept to use in eliminating certain types of known CMF initiators from consideration.

Statistical confidence concepts

Another point of interest is the use of high-level S-confidence bounds. Conceptually, the ideas of statistical confidence are most meaningful in sampling theory where one wishes to have information about a population (or lot) by sampling a relatively small portion. Here also the basis is that the underlying phenomena remain the same from sample to sample. If this were not true, any fixed sampling procedure would be invalid. It also has little meaning when one is sampling every member of the population (as one does with scrams). For this reason, the choice of any very high S-confidence level based only on previous failures that have been rectified is highly conservative.

The quantification of this discussion in Table 1 illustrates what a realistic treatment of the data implies.

The use of a median S-confidence limit of 50% is not arbitrary on our part but is consistent with Regulatory Guide 1.108, which describes an acceptable statistical scheme for testing diesel generators. The implications of the above calculation are that on the basis of data alone, WASH-1270 was conservative by a factor of 50 in its calculation of the RPS unavailability per demand.

One need not rely on data alone to make an estimate of the statistical properties of the RPS. Obviously, before the first RPS is installed we have almost no data, and for systems with great reliability, (due to redundancy, for example) it may be many years or even centuries before sufficient data to yield "good" statistics are accumulated. Normally, we make use of engineering judgment, heavy over-design, modeling studies, and so on, to give us confidence that the system will do its job. It is possible to incorporate such information into a more elaborate statistical treatment by means of Bayesian estimation. We shall return to this later.

The upperbound number 3×10^{-6} per demand for RPS unavailability is quite low, and if we multiply it by 1 or 2 for the upperbound on total event yearly frequencies, we still have a low number. But not yet 10^{-7}. Let us now ask a few more questions. Whatever the ATWS number may be—does that imply that we should expend time and effort to make the number smaller? What about priorities? What benefit accrues to the public if we wipe out

Table 1

RPS UPPERBOUND UNAVAILABILITY

(per demand, based on data alone)

	50% S-confidence	*95% S-confidence*
WASH-1270	3.8×10^{-5}	1.6×10^{-4}
WASH-1270 (update to 1976)	2.1×10^{-5}	8.9×10^{-5}
EPRI (1976 evaluation)	3.0×10^{-6}	1.3×10^{-5}

ATWS? How do we get a handle on these questions?

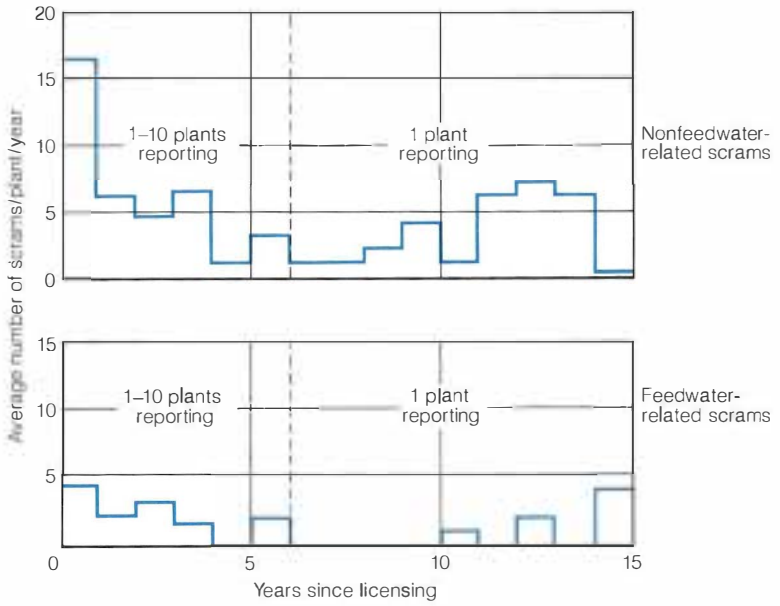
WASH-1400 contains all the information needed to answer these questions. WASH-1400 considered all the possible ways (or as many as the authors could think of) that a reactor could undergo a trauma of sufficient magnitude for extensive core damage to result with a greater or lesser release of radiation, and it incorporated meteorological effects to carry the radiation into the off-site ecosystem. Since the authors also included ATWS events in their analysis, in WASH-1400 we have a basis for establishing what portion of the total risk (expressed, for example, as a 30-day whole-body dose in rem at the exclusion boundary) is attributable to ATWS. We can also determine the probability of violating 10CFR-100.

To be able to defend the ATWS results of such an editing of WASH-1400, the reappraisal group reconstructed all the fault trees considered important. No significant changes were discovered to be needed during this reconstruction. It was found that updating the data and modifying one statistical model were all that was necessary. The results of this work show that the percentage of risk attributable to ATWS (based on WASH-1400 updated) is, for PWRs, only 0.5%; for BWRs, 5.0%.

Risk studies of this type yield information on whether a particular component, subsystem, or system should perhaps be redesigned or backfitted to increase reliability. From the viewpoint of cost-benefit–risk considerations, it would seem that a situation responsible for less than 5% of the total potential risk (measured in man-rems, 30-day whole-body dose) would not be an early candidate for either redesign or backfitting unless the costs were low enough to make it an incidental expense.

One might conclude that BWRs have 10 times the ATWS risk of PWRs, but careful examination of the data input to the fault trees from areas where we were unable (because of the need to preserve a balanced estimate) (*4*) to alter data input shows sufficient conservatism to smooth out this difference.

Figure 2 The learning curve with an average PWR also shows a fall in scram initiators per year, but distinction must be made between those that involve a loss of feedwater and those that do not.



Probabilities determined

In a second edit of the WASH-1400 data, we determined the probability of violation of 10CFR-100. For this study we were no longer interested in comparing one portion of the risk fraction with another; hence we could consider updating more of the data than in the risk comparison. For example, WASH-1400 assumes 10 transients per year with a range of 5–20. Figure 1 shows that these numbers should be closer to 2.5/yr with a range of 0–5 for BWRs. Figure 2 shows that PWRs exhibit the same sharp fall in scram initiators per year as BWRs, but here we have to discriminate between scram initiators involving loss of feedwater and no loss of feedwater. The former have a long-term expected average of about 1/yr, while the latter have an average of about 4/yr and the ranges are about 0–2 and 0–8.

Another type of update has to do with the RPS failure probability for the two types of reactors. In each case, WASH-1400 used schematic diagrams to construct a fault tree that models the RPS system. We corroborated these trees.

In quantifying the trees further, modeling of such phenomena as common-mode miscalibration of instruments and test and maintenance errors had to be made. In both cases (instrument miscalibration for BWRs and testing and maintenance for PWRs), the quantifications are strongly conservative—so much so that the RPS unavailability is completely dominated by these items (93% for PWRs and 98% for BWRs). The hardware and electronics are responsible for essentially none of the unavailability. It is not difficult to attack these aspects of the input data, but it is not terribly important to do so at the present time. The BWR modeling yields results consistent with the EPRI (rectified) case in Table 1, while the PWR yields unavailabilities that are a factor of 6 or more larger than the scram data alone would imply. In any event, if we incorporate the latest values for the expected number of transients and the modeled estimates for scram unavailability, we can use the WASH-1400 consequence model and determine the median upper-bound probabilities of exceeding 10CFR-100. For PWRs, this probability per year is 1.7×10^{-7}; for BWRs, 7×10^{-7}.

These both far exceed the 25-rem two-hour iodine thyroid dose. If we considered the other aspects of 10CFR-100 we should in all cases find much lower values. One sees here that based on a common quantified consideration, the PWR and BWR achieve a closer comparison. Since the input to these calculations is, in our estimation, quite conservative, we would expect both these numbers to drop and perhaps still show a difference between reactor types, but at this low level of probability, further pencil-sharpening seems wasted.

Table 2
SUMMARY OF MEDIAN RPS UNAVAILABILITIES PER DEMAND AND THE EFFECT ON 10CFR-100 VIOLATION

Reactor	*WASH-1270*	*WASH-1400 (updated)*	*EPRI*	*EPRI Bayesian Estimate*	*EPRI Bayesian Probability of 10CFR-100 Violation (per year)*
BWR	3.8×10^{-5}	2.3×10^{-6}	3×10^{-6}	3.4×10^{-7}	3.3×10^{-7}
PWR	3.8×10^{-5}	5.1×10^{-5}	3×10^{-6}	9.0×10^{-6}	7.7×10^{-8}

One further aspect should be considered. The fault tree models for RPS unavailability used in the WASH-1400 studies are based on a very small fraction of the information used to establish Table 1. Because of this we can enfold the two results through use of the Bayes equation to produce a more sophisticated estimation of scram unreliability *(5)*. If we do this, we obtain the results shown in Table 2.

ATWS is a nonproblem

The results of these studies indicate to the people who did them, as they do to the writer, that except for assurances that the WASH-1400 analysis applies to other reactors (the BWR had a recirculation pump trip, for example, which does not appear in some of the older BWRs) ATWS is a nonproblem with a probability of occurring that is terribly small and an even smaller probability of significantly affecting the health and welfare of the public.

Still, one might reasonably ask, How difficult and expensive would it be to eliminate ATWS apart from any other considerations? And as a corollary, ask, What benefits can be expected to accrue to the public (who in the end must pay for any such design modifications)? For a number of years, members of the NRC staff have estimated that a complete ATWS "fix" would cost only a few hundred thousand dollars, while vendors have felt that it would cost a few million dollars. This difference was due to the fact that no one had put together an actual cost estimate of backfitting a plant. Because NRC has required each plant to submit proposed plant design revisions, it is now possible to establish actual cost estimates. These range from $20 million to $50 million per plant. The dollar costs, then, are very high.

If the purpose of WASH-1270 was to establish that ATWS is indeed real enough to require regulation, it arrived at an erroneous conclusion because the results presented here, insofar as they demonstrate probabilistics in the neighborhood of 10^{-7}/yr, contradict WASH-1270. Further, the technical basis for arriving at these results is much more extensive and better documented than that in WASH-1270.

There are, however, those who maintain a "hang the cost" attitude and would require elimination of ATWS, no matter what. If their view prevails, then the public will pay to eliminate a nonproblem.

Notes and references

1. S-confidence is a mathematical term meaning the probability that the value of a parameter (in this case, a failure rate) is less than some specified amount. One can write it in this case as P (rate is less than 1.6×10^{-4} per demand) = 0.95. The actual value of the rate may lie anywhere between zero and 1.6×10^{-4} per demand without altering the value of the right side of the equation.

2. Such replacements are made on a scheduled basis.

3. U.S. Atomic Energy Commission. "Instances of Relay Failure in Reactor Protection Systems." *Reactor Safety Operating Experiences.* ROE 71-16, AEC 1971.

4. Since a comparison was being made between the ATWS portion of risk and the total risk estimate in WASH-1400, it was not possible to alter values in the ATWS calculation that would induce alterations in the rest of the risk calculation (funds, manpower, and time available provide constraints).

5. The Bayesian approach is based on the concept of conditional probability (given that A is true, what is the probability of B occurring). Thus it is possible to incorporate different types of probability estimates of the same phenomena to produce a single overall estimate. The ease of such incorporation is enhanced by the independence of the original estimates.

New Technical Reports

Each month the JOURNAL publishes summaries of EPRI's most recent reports. Supporting member utilities receive copies of reports in program areas of their designated choice. Supporting member utilities may order additional copies from EPRI Records and Reports Center, P.O. Box 10412, Palo Alto, CA 94303. Reports are publicly available from the National Technical Information Service, P.O. Box 1553, Springfield, VA 22151.

ELECTRICAL SYSTEMS

The Automated Distribution System: An Assessment of Communications Alternatives

EL-157 Final Report (2 Vol.) (RP569)

This overview of an analysis of the detailed technical communications requirements of the Automated Distribution System (ADS) principally assesses available communications options. The study developed a methodology for evaluating candidate techniques. Essential, detailed technical discussion is deferred to the appendices, but most of the supporting analysis has been omitted from the body of this report. *MITRE Corp.*

Analysis of Forced Cooling of Compressed-gas-insulated Transmission Lines

EL-228 Final Report (RP7840-1)

The objective of this project is to make a thermal and cost analysis of forced cooling of buried compressed-gas-insulated transmission lines (CGIT). Only direct cooling of the sheath is considered, with water coolant flowing in aluminum pipes integrally extruded or directly bonded to the CGIT aluminum sheath. This technique is suitable for direct application with conventional CGIT lines, with no modification of the basic design. Both isolated-phase and three-conductor CGIT systems are considered, with maximum voltage rating from 145 kV to 1200 kV. The lines have aluminum conductors and sheaths and are filled with SF_6 at a pressure of 50 psig. The total system costs of installing buried, forced-cooled CGIT lines are calculated for the isolated-phase and for three-conductor CGIT lines for 145 kV to 1200 kV at the various current ratings. *Westinghouse Electric CGIT Laboratory*

U.S. Transformer Oil Supply and Demand

EL-303 Interim Report (RP562-1)

This report provides a forecast of the naphthenic transformer oil supply and demand compared with estimates for the next decade. There is a substantial prospect of shortfall in supply between 1980 and 1985. Present production is such that the projected average life of U.S. reserves will extend to about 1983. It appears that the majority of naphthenic crude is either going to other uses or is not segregated in transport. The present and forecast supplies of alkyl benzenes and polydimethylsiloxanes (silicones) represent possible, although unproven, alternatives to naphthenic transformer oil.

The high cost of new facilities, the long lead time from the planning of new plants to their completion, the relative small volume of the transformer oil market, and the cost and time required to fully test new oil types and additives—all point to the vital necessity for continuing study by the producers, the equipment manufacturers, and the utility companies to arrive at optimal solutions to the problems of oil supply during the critical period in the years ahead. *General Electric Co.*

ENERGY ANALYSIS AND ENVIRONMENT

A Comparative State-of-the-Art Assessment of Gas Supply Modeling

EA-201 Final Report (RP436-1)

This report presents a state-of-the-art comparison of twelve major gas supply modeling efforts in three general categories: (1) structural models of resource economics, (2) pure econometric models, and (3) resource base–geologic models.

Parts I and II provide a detailed discussion of the natural gas supply sector. Part III defines the elements of the gas supply process as well as the chronology of gas supply modeling efforts and the characteristics that distinguish them. Part IV summarizes and reinforces the observations presented for each model individually in Part III and presents a concise reiteration of model strengths and weaknesses, alternative projections and forecasts, and the implications of these methodologies for future research and policy analysis. Part V concludes with a succinct statement concerning the state of the art and recommendations for steps to be taken in future research efforts in this area. *Mathematica, Inc.*

Long-range Forecasting Properties of State-of-the-Art Models of Demand for Electric Energy

EA-221 Final Report (2 Vol.) (RP333)

This report evaluates the long-range forecasting effectiveness of selected econometric models of the demand for electric energy. An annotated bibliography of long-term electric energy forecasting models is presented in a separate volume. The eight models tested represent those specifications and other features of extant models believed to be of potential use in developing improved models for long-range forecasting at national and regional levels.

Each model is replicated, reestimated on a common data set, and tested for performance: forecast and backcast accuracy, parameter stability over time, robustness of parameter estimates to small changes in specification or variable measurement, consistency and plausibility of model results, and quality of model test statistics. The final chapter presents recommendations for near-term and longer-range improvement in the state of the art.

The effectiveness of all the models is limited by the quality of the available data and their reliance for estimation on pooled cross section/time series of statewide aggregate measures during a period of relatively smooth growth. The resulting problems of multicollinearity and lack of observed variance in key variables contribute to uncertain and unstable estimates. *Charles River Associates, Inc.*

Reactions of Nitrogen Oxides, Ozone, and Sulfur in Power Plant Plumes

EA-270 Final Report (RP572-3); Interim Report (RP330-1)

Potentially harmful chemicals (so-called second-generation products) may be generated in the plumes from fossil fuel power plants as they react with ambient air. Two chemical species in particular are commonly mentioned in this respect: ozone and sulfate aerosol. Although fossil fuel plants do not emit either chemical directly into the atmosphere, they do generate and emit potential ozone and sulfate precursors that can react with chemicals to form second-generation products in the air.

The present report is concerned mainly with the results obtained on studies of ozone in power plant plumes; aerosol production is discussed only briefly. More detailed field and theoretical studies on this subject will be reported in a future EPRI report. Thirty sets of airborne measurements were obtained in the plumes from two coal-fired and two gas-fired power plants situated in different climatological areas. *University of Washington*

Conclusions and Recommendations on Supplementary Environmental Control Systems

EA-279-SR Special Report

A workshop on supplementary environmental control systems was held in Hartford, Connecticut, June 10–11, 1976. The purposes of the workshop were to review the present and future status of supplementary environmental control systems (SECS) as an air pollution control strategy for fossil-fueled electric power plants, and to prepare recommendations on the future course of any R&D programs EPRI might develop on SECS.

An Input-Output Analysis of Energy Use Change, 1947–1958, 1958–1963, and 1963–1967

EA-281 Final Report (RP441)

Through the use of input-output techniques, it is possible to resolve changes in the energy consumption of a sector between two years to reflect changes in technoeconomic factors (as represented by the input-output coefficients) resulting in changes in the final demand for sector output.

This report presents a computation of the energy used to produce a real-dollar output in 1947, 1958, 1963, and 1967 for 30 energy-consuming sectors. The energy used by 4 energy-producing sectors to produce a given amount of energy output is also calculated. Similar computations are presented per unit of final demand. Some sectors, such as rubber and miscellaneous plastics, show a continuing decrease in the amount of energy required per unit of output or final demand. A number of sectors, such as agriculture, showed decreasing energy intensity through 1963 and greater energy intensity in 1967. The increase in total energy consumption between 1963 and 1967 would have been more than twice as great, assuming the same bill of goods were produced in the same manner, if there had not been a marked increase in efficiency in the economy as reflected in technoeconomic coefficients. *Battelle, Pacific Northwest Laboratories*

Energy Input-Output Modeling: Problems and Prospects

EA-298 Final Report (RP208-1)

Recent research has focused on the relationship between energy and other sectors of the macro-

economy. One outgrowth of this research has been energy input-output (I-O) tables, which, unlike conventional I-O tables, focus on physical flows of energy through the macroeconomy. The first concern of this paper is to investigate the methodological differences and empirical justification for the use of physical energy I-O coefficients as opposed to conventional I-O coefficients, which rely on real dollar flows.

The second concern is to review energy-oriented applications of I-O analysis, including applications based on physical and on real dollar flows. These studies range from static energy I-O coefficient analysis of the Btu content of an auto to efforts to dynamize I-O models by allowing the coefficients to change in response to relative prices and technology. The coefficient modeling techniques of the latter range from process-oriented optimization techniques to new econometric techniques. A third focus of the report is to analyze how energy I-O coefficients might be utilized with respect to the Wharton Annual Model; three alternative applications are investigated and a research strategy is suggested. *General Electric Co.*

Sulfur Oxides: Current Status of Knowledge

EA-316 Final Report (RP681-1)

The report is a state-of-the art review on sulfur oxides, including sulfur dioxide, sulfurous and sulfuric acid, sulfates, sulfites, and bisulfites. The report considers the interaction of sulfur oxides with other pollutants that may be associated with health impacts. The major topics of discussion are the toxicological assessment, the human clinical assessment, and the epidemiological assessment of sulfur oxide health effects. Special consideration is given to the sulfate–health effects issue, with emphasis on the identification of gaps in existing knowledge. Suggestions are offered for future research programs. *Greenfield, Attaway & Tyler, Inc.*

FOSSIL FUEL AND ADVANCED SYSTEMS

Assessment of Laser-driven Fusion

ER-203 Final Report (RP470-1)

This final report presents details of the national fusion program as of March 1976. It includes a general summary by the Laser Fusion Advisory Committee and a summary by the working group. The detailed scientific and technical evaluations of the national laser fusion program are presented in four parts: an overall assessment, engineering feasibility, scientific feasibility, and site visits. *K. A. Brueckner & Associates, Inc.*

Evaluation of Dry Alkalis for Removing Sulfur Dioxide From Boiler Flue Gases

FP-207 Final Report (RP491-1)

This report involves a review and evaluation of particulate and dry scrubbing processes by injection of alkali powder, particularly nahcolite, into furnace or boiler flue gases. Also included is a review of the earlier work at the Mercer Station of the Public Service Electric and Gas Company of New Jersey. The principal points covered in the evaluation are the chemistry, mining, transportation, waste disposal, and economics of the several processes reviewed. Data reflecting the influence of nahcolite and other dry alkalis upon the reduction of NO_x emissions are also included. Finally, a recommendation is made as to what additional bench-scale and prototype investigations need to be conducted to fully demonstrate the technology.

Although some of the basic technology for dry scrubbing of stack gases is the confidential property of certain firms, the pertinent information in this report has been released by them for EPRI's use. Some additional detailed information may be acquired from the participants on an individual basis and with appropriate secrecy agreements. *Bechtel Corp.*

Hydrogen Production From Coal Liquefaction Residues

AF-233 Final Report (RP714-1)

High-ash H-Coal residues from the liquefaction of Illinois No. 6 and Wyodak coals were gasified in a Texaco synthesis gas generator at Texaco's Montebello research laboratory. The synthesis gas produced consisted of over 92 volume/% carbon monoxide (CO) and hydrogen (H_2) on a dry basis. Enough data have been obtained to verify existing computer correlations and to establish information needed to provide a commercial plant design for these two, and other similar, coal liquefaction residues. *Texaco, Inc.*

Enhanced Energy Utilization From a Controlled Thermonuclear Fusion Reactor

ER-248 Final Report (RP471-1)

Unique forms of fusion energy may be applied to synthetic fuel production, chemical manufacturing, and materials processing. This study has developed computer codes for quantitative calculation of the enhancement of energy utilization efficiency for multipurpose tokamak and mirror reactors. The most important near-term application identified was production of synthetic portable fuels such as hydrogen or methane by neutron radiolysis. Fuel production offers large advantages for low-Q, high-circulating power systems such as mirrors, small tokamaks, theta pinches, and laser pellet reactors. It offers little advantage to high-Q, high thermal efficiency systems typified by large tokamaks. A small (5-m in length) mirror could be operational by 1986, producing net useful energy at 6.5% efficiency. It is recommended that research begin immediately on 14-MeV neutron radiolysis as well as on blankets designed for radiolytic production of fuel. General descriptions are given of the unique energy forms of a fusion reactor as well as the many processes that these energy forms could promote. *Fusion Systems Corp.*

Evaluation of a 1-kWh Zinc Chloride Battery System

EM-249 Interim Report (RP226-1)

A 1-kWh zinc chloride battery has been constructed and evaluated for 100 cycles to determine the technical feasibility of this battery system for utility application. The battery was tested under operating conditions appropriate to the peaking application—approximately a 4-hour charge, 4-hour discharge cycle. The battery system uses zinc and chlorine as the active electrode materials, employs an aqueous circulating electrolyte, and is operated near ambient temperature. The chlorine is stored outside the battery as chlorine hydrate. The results of this study demonstrate the technical feasibility of the zinc chloride battery for utility application. The high electrochemical energy efficiency is consistent with the goals for this application. This high energy efficiency and the stability of performance through the 100 charge and discharge cycles suggest this battery is an attractive candidate for development into a utility energy storage system. *Energy Development Associates*

Engineering Design and Cost Analysis of Chlorine Storage Concepts for a Zinc-Chlorine Load-leveling Battery

EM-259 Final Report (RP731-1)

In the zinc-chlorine battery, chlorine (the positive active-electrode material) must be stored outside the electrochemical converter. Chlorine can be stored in one of several ways: (1) as a pressurized liquid, (2) as chlorine hydrate (a solid water-chlorine ice), and (3) reversibly bound to organic compounds, such as carbon tetrachloride. The objective of this project was to evaluate and compare alternative chlorine storage approaches in terms of the key technical, safety, economic, and environmental aspects. The study has demonstrated that for an ambient pressure zinc-chlorine battery, chlorine hydrate is a simpler and less expensive storage method than liquid chlorine. Adequate energy efficiencies could not be obtained for the battery system using an absorption of chlorine in carbon tetrachloride. *Bechtel Corp.*

Study of Fast Magnetosonic Wave and Neutral Beam Heating of Large Tokamaks

ER-268 Topical Report (RP237-3)

This publication reports on studies of wave and neutral beam heating of tokamak plasma. The leading wave heating candidates include low-frequency Alfvén waves, fast magnetosonic waves, lower hybrid waves, and electron cyclotron waves. The use of fast magnetosonic waves in heating a tokamak reactor to ignition receives detailed consideration, including a description of a conceptual launching system compatible with reactor plasmas. A description of neutral beam heating includes requirements on injection energies and the resultant heating profiles for reactor plasmas. Finally, the advantages and problems of both the radio-frequency (RF) and neutral beam heating methods are compared. Neutral beams enjoy a very good agreement between present theory and experiment. However, potential penetration and heating of the plasma core and the required source development for reactors favor RF heating. *University of Wisconsin*

AC/DC Power Conditioning and Control Equipment for Advanced Conversion and Storage Technology

EM-271 Final Report (RP390-1)

This report presents the results of the work performed since the publication of the key phase report for this project in August 1975. The two most likely long-range candidates for converting dc to ac power from batteries and fuel cells are the basic current-fed line commutated inverter (a derivative of HVDC technology) and the voltage-fed conduction angle controlled force commutated inverter. Results are presented for analysis of cost, performance, and reliability which lead to the identification of the current-fed line commutated technology as the most promising long-range choice. This conclusion is drawn for characteristics of today's solid-state devices, as well as for forecast improvements in those characteristics. *Westinghouse Electric Corp.*

Program of Research on Steel for Utility Applications

FP-274-SR Special Report

Steel is the most used and probably the single most important construction material in electric utility plants. For this reason, improvements in steels offer enormous potential for greater efficiencies

in fuel utilization, particularly of coal. EPRI held a workshop in December 1974 to draft specific research objectives and programs for the design of better steels. Suggestions for research emphasized problems of reliability, availability, and forced outage, including: long-term susceptibility to embrittlement or strength degradation; elevated-temperature properties of weldments; possible synergism of erosion/corrosion in advanced coal-conversion technologies; degradations engendered by cyclic operations; and quality assurance methodologies.

With the workshop recommendations as a guide, EPRI has implemented an R&D program for improved steels largely in the Fossil Fuel and Advanced Systems Division. This report describes individual project elements of the program.

Design and Cost Estimate of a 20-ton/h Pulverized-Coal, Suspension-Type, Pressurized Gasification System Test Facility

AF-277 Final Report (2 Vol.) (RP266-1)

Babcock & Wilcox Co. has completed the design and cost estimate of a 20-ton/h, pulverized-coal, pressurized entrained gasification system. The system has been designed to operate with air, oxygen-enriched air, or pure oxygen as the oxidant. The scope of the system design includes all the equipment from coal preparation to utilization of the gas fuel produced. The design is site-specific to the Seward station of the Pennsylvania Electric Co.

The gasification system is designed for a wide range of operating conditions. When using air as the oxidant, the fuel gas produced will have a heating value of approximately 100 Btu/scf. When operating with oxygen, the heating value of the fuel gas will be approximately 300 Btu/scf. Both of these product fuel gases are suitable for burning in an existing boiler at the Seward station. *Babcock & Wilcox Co.*

Tritium Inventory Considerations in Fusion Reactors

ER-278 Topical Report (RP236-1)

This report presents a model for the determination of the tritium inventory based on system operating parameters. These include tritium burnup rate, tritium production rate, and various residence times of tritium in plant systems. Upon review of various proposed blanket designs and tritium purification and separation systems, a plant is chosen and the total tritium inventory associated with this design is calculated. A parametric study demonstrates how system residence times and reactor operating parameters affect the plant inventory. *University of California at Los Angeles*

Proceedings of First Semiannual EPRI Solar Program: Review Meeting and Workshop

ER-283-SR Special Report (2 Vol.)

EPRI has funded an extensive R&D program to define and develop solar energy systems that incur the lowest cost when integrated with utility networks, and to define the impact of solar energy system interactions with these networks. EPRI sponsored the first semiannual program review meeting and workshop in San Diego, California, March 8–12, 1976.

These volumes constitute the proceedings of the meeting. Volume 1 is concerned primarily with solar heating and cooling. It includes a short overview of the ERDA program and reports on the EPRI-sponsored work in insolation data evaluation and in materials and components testing. Volume II is concerned primarily with solar electric power and environmental impact of various solar plants.

Synthetic Electric Utility Systems for Evaluating Advanced Technologies

EM-285 Final Report (TPS75-615)

Systematic assessment of alternative new technologies and new developments on utility systems is important. One approach to making systematic, generic assessments is to use the methodology of utility system planning engineers, such as load flow and stability calculations for transmission facilities, and power production and reliability analysis for generation facilities. However, it is neither feasible nor necessary to make such generic assessments on large, detailed models of the U.S. power system. Instead, a practical solution is to use smaller, synthetic utility systems with characteristics representative of various portions of the U.S. utility system.

This report presents the results of the first step in the development of a systematic method of evaluating alternative new technologies on the U.S. power system: the development of representative scenario systems and data. Six generation and transmission scenarios, a "plug-in" distribution system, and typical data for utility system components have been developed. These systems and data are broadly representative of utility system characteristics as they are projected for the mid-1980s. *Power Technologies, Inc.*

Development Program for an Ionizer-Precipitator Fine Particle Dust Collection System as Applied to Coal-fired Utility Steam Generators

FP-291 Final Report (RP386-1)

This report summarizes work conducted by APS, Enviro Energy Corp., and Kaiser Engineers. The work was directed at developing more effective electrostatic precipitation of fine particulate, especially of high-resistivity fly ash, by imposing a higher degree of charge on the particles. A unique electrode assembly results in an intensely ionized flue gas that leads to a particle charge as much as four times greater than is currently being achieved. Such an ionizer would be the first or charging stage of an improved two-stage power station electrostatic precipitator immunized against high-resistivity dust.

Generally, laboratory analysis and testing have provided the data necessary to proceed with the design of a larger-scale field pilot. Economic evaluations of the concept based on laboratory data are included. Possible mechanical arrangements for incorporating the high-intensity ionizer into conventional design precipitators are indicated for both new and retrofit installations. Small-scale field pilot work was undertaken at an operating utility to supplement laboratory work. *Air Pollution Systems, Inc.*

Reaction of Silicon Carbide With Fused Coal Ash

AF-294 Final Report (TPS76-623)

Studies have been made of the reaction of two grades of commercial silicon carbide (Carborundum KT and Super KT) with acid and basic fused coal ash slags in a synthetic coal combustion atmosphere. Computer calculations of chemical equilibria predicted a thermodynamic instability of the carbide in this environment. However, experimentally observed reaction rates were found to be exceedingly slow in either acid or basic ash slags. Both grades of silicon carbide were found to have equally good long-term resistance of the SiC phase to corrosive attack by either sintered or fused ash at temperatures to 1250°C (basic ash) and 1450°C (acid ash). *Lockheed Palo Alto Research Laboratory*

EPRI Regional Seminars on the Environmental Control and Combustion Program

FP-295-SR Special Report

EPRI held a series of ten regional seminars on the Environmental Control and Combustion Program with member utilities. The purpose of the seminars was to provide sponsoring companies with a first-hand opportunity to review and discuss the program. They also provided the EPRI technical staff with additional insight into environmental control problems and research priorities as seen by the power production and engineering/R&D departments of the utility industry.

The utilities recommended increased R&D emphasis on problems affecting the near-term operation of existing and planned power generation capacity. Their recommendations focused on improved water quality control technology and on improved performance and reliability of combustion as well as environmental control equipment.

Determination of the Fractional Efficiency, Opacity Characteristics, Engineering and Economic Aspects of a Fabric Filter Operating on a Utility Boiler

FP-297 Final Report (RP534-1)

The fabric filter baghouse of the Nucla Station, Colorado-Ute Electric Association, Inc., was evaluated with a field performance test and engineering analysis. The overall collection efficiency determined with impactors was 99.92% at 12 MW, with outlet mass concentrations of less than 0.0011 gr/ft^3. The outlet capacity was measured to be less than 1%. The unit capital cost (including all retrofit construction costs related to the collector) was $87/kW. The operating costs are 1.53 mills/kWh for 1976 based on a 55% capacity factor. The installation of thimble flow straighteners reduced premature bag failures due to bag erosion. The bag replacement was 18% of the total during the first two-year period (most of this was prior to installation of the thimbles). The unit availability has been 100% since installation, and the compartment availability has been 99.8% *Meteorology Research, Inc.*

Geotechnical Environmental Aspects of Geothermal Power Generation at Heber, Imperial Valley, California

ER-299 Topical Report 1 (RP580)

This report presents a portion of the results from a one-year study to assess the feasibility of constructing a 25–50 MWe geothermal power plant using low-salinity hydrothermal fluid as the energy source. The objective of this part of the study was to investigate the geotechnical aspects of geothermal power generation and their relationship to environmental impacts in the Imperial Valley of California. This report discusses geology, geophysics, hydrogeology, seismicity and subsidence in terms of data availability, state-of-the-art analytic techniques, historical and technical background, and interpretation of current data. It also discusses impact estimates of these geotechnical factors on the environment of the Imperial Valley, if geothermal development proceeds. *Geonomics, Inc.*

Energy Conversion and Economics for Geothermal Power Generation at Heber, California; Valles Caldera, New Mexico; and Raft River, Idaho—Case Studies

ER-301 Topical Report 2 (RP580)

This report presents a portion of the results from a study to assess the feasibility of constructing a 25–50-MWe geothermal power plant using low-salinity hydrothermal fluids as the energy source. The objective was to investigate the compatibility of the different power conversion options with real geothermal reservoirs and to analyze the economics of power generation.

Three sets of conversion technology are considered for the near term: flashed steam, binary, and hybrid (flashed steam/binary). Reservoir and geothermal fluid characteristics have a strong influence on (1) choice of conversion technology, (2) performance and life of materials and components, (3) necessary environmental controls, and (4) ultimate cost of generating power.

This report discusses nine cases chosen to yield further insight into the effect of reservoir temperature on the choice of conversion technology and power costs. The cases examine flashed steam, binary cycle, and hybrid conversion for Raft River, Idaho; Heber, California; and Valles Caldera, New Mexico. Bottom-hole temperatures are approximately 150°C, 180°C, and 260°C respectively. Conceptual layouts of the power conversion processes, cycle analysis, and economic analysis are presented.

The principal conclusions are: (1) a hydrothermal demonstration plant is technically, environmentally, and economically feasible in the 1980s; (2) the recommended demonstration site is Heber, Imperial Valley, California; (3) binary cycle power conversion technology is recommended; (4) the recommended demonstration plant capacity is approximately 50 MWe; and (5) there are no overriding environmental constraints. *Holt/Procon*

Proceedings of an EPRI Workshop on Technologies for Conservation and Efficient Utilization of Electric Energy

EM-313-SR Special Report

This EPRI workshop took place in San Diego, California, July 26–30, 1976. Twenty-seven working papers were presented in six topical areas: overview and objectives; physical bases for efficient energy use; industry's needs for efficient electricity use and implications for R&D; energy use regulations impacting the electric utilities; utility views and programs, and implications for EPRI's role, in efficient electricity use; and R&D needs and opportunities. Appendix B contains summaries of the daily sessions and a special session in which an overall summary and preliminary R&D priorities were developed.

Advanced Steam Cycles Using Fluidized-Bed Steam Generation and Heating: Task I

FP-317 Final Report (RP582-1)

In pulverized-coal-fired boilers, an upper limit to attainable steam temperature is imposed by the deposition of slagged ash and corrosive material on superheater tubes. This corrosive material derives from mineral impurities in the coal, which form complex salts after being heated to 2500–3000°F in the flame. The maximum temperature in a fluidized bed is about 1600°F—low enough to inhibit formation of corrodents and prevent the melting of ash. It has been suggested that the fluidized-bed boiler might open the way to more efficient steam cycles, using higher temperatures.

This project was initiated to see if other factors, particularly in the steam turbine, would restrict the development of advanced steam plants, using existing or near-future technology. The study shows that the major obstacle is the fabrication of very large, high-quality rotor forgings in "super alloys" suitable for high-temperature service. *United Engineers & Constructors, Inc.*

Proceedings of the Workshop on Analysis of 1974 and 1975 Power Growth

EA-318-SR Final Report

The papers in this volume examine the causes of the low rate of growth in electric power output in 1974 and 1975. The subject is examined at various levels of aggregation by representatives of various institutions, including individual electric utilities. Perspective on national and regional growth is provided by: a firm of economic consultants to the utility industry, power equipment manufacturers, a regional electric reliability council representative, an ERDA staff member, and an EPRI econometrician. The relationship between electricity output and the index of industrial production is discussed by a representative of the Federal Reserve Board.

The papers cover a geographic cross section of the industry with varying concentrations of urban and rural loads and varying loads in the residential, small light and power, and industrial power categories. This collection represents a rich source of material for utility analysis and assessment of the forces changing industry growth patterns. Observations and findings are presented in a summary paper by Edison Electric Institute authors.

NUCLEAR POWER

Fracture Toughness Data for Ferritic Nuclear Pressure Vessel Materials

NP-121 Final Report (RP232-1)

The Appendices presented in Volume II represent the detailed analysis of approximately 20,000 experimental test results. Volume I familiarizes the reader with the overall program and objectives, presents the analytic tools developed for statistically analyzing the data, and provides specific examples for the interpretation of the data in Volume II. Volume I also contains the conclusions and recommendations reached after the data were analyzed. *Effects Technology, Inc.*

Evaluation of Scale-Model Methods for Operability Qualification of Seismic Category I Pumps and Valves

NP-174 Final Report (RP398-1)

Seismic qualification of some critical equipment for nuclear power plants can have a significant influence on design. Operability requirements for large pumps and valves as defined in the NRC Regulatory Guide 1.48 do not provide specifics on the seismic qualification approach. Justification of a specific approach remains the responsibility of the manufacturer, who is faced with limitations in testing facilities and scale-model requirements.

The objective of this project is to determine the extent to which scale-model testing can be used to simulate the seismic response of Category I pumps and valves. The scope of the study includes: a literature search to determine existing technology on scale-model testing, the evaluation of critical operability parameters and associated testing, the evaluation of scaling laws applicable to operability testing, and associated manufacturing and testing costs. The results may provide useful background information for anyone contemplating scale-model tests during the qualification process. However, the study identified several limitations of scaling techniques and test capabilities that need to be resolved before an extensive model test program can be justified. *Wyle Laboratories*

Two-Phase Pump Performance Program: Pump Test Facility Description

NP-175 Key Phase Report (RP301-1)

A description is given of the two-phase pump performance project test facility located at the Kreisinger Development Laboratory of Combustion Engineering, Inc., Windsor, Connecticut. The text outlines and describes the physical system that constitutes the facility, as well as the specific pump being tested in the EPRI program. Considerable emphasis is given to a description of the test instrumentation and calibration and to the procedures for data acquisition and acceptance. *Combustion Engineering, Inc.*

Analysis of Select Mod-1 Semiscale Blowdown Heat Transfer Tests

NP-206 Final Report (RP445-1)

This report contains the RELAP-4 analysis and sensitivity studies of semiscale tests S-02-2 and S-02-7 performed prior to the prediction of Standard Problem 5 as reported in NP-212. The semiscale system is an electrically heated experiment designed to produce data on performance typical of PWR thermal-hydraulic behavior. The RELAP-4 program used for these analyses is a digital computer program developed to predict the thermal-hydraulic behavior of experimental systems, water-cooled nuclear reactors subjected to postulated transients, etc.

The results of the analysis of test S-02-2 revealed two parameters that required improvement: the lower plenum density and the mass flow on the vessel side of the break. Before analyzing test S-02-7, the lower plenum was renodalized and the critical flow model at the vessel side break was modified. The results of the analysis of test S-02-7 compared more favorably with the data than those of S-02-2.

Additional sensitivity studies included time step studies, steam generator and downcomer modeling, and core nodalization. *Energy Incorporated*

Studies of Thermal Reactor Benchmark Data Interpretation: Experimental Correction

NP-209 Final Report (RP247)

Whether a nuclear cross section data library is adequate for power reactor applications can be determined from calculations using it to predict the behavior of specially designed experiments. These benchmark experiments must be designed in a way that will minimize uncertainties in the measured quantity due to the experimental configuration as compared to uncertainties introduced by the nuclear data. They are thus carried out in characteristic but simple geometries (repeating "infinite" lattices). Reported results are corrected for perturbations introduced into the system by detector foils and other experimental apparatus.

The Cross Section Evaluation Working Group (CSEWG), which is responsible for the develop-

ment of the national reference nuclear data library (ENDF/B), has selected seven critical lattice experiments to be used as thermal data testing benchmarks. The objective of this study has been to use a consistent set of primarily Monte Carlo techniques and the most recent data to recalculate the various corrections applied by the original experimenters to their raw foil activation data. *Stanford University*

A Prediction of the Semiscale Blowdown Heat Transfer Test S-02-8 (NRC Standard Problem 5)

NP-212 Key Phase Report (RP445-1)

This report contains the RELAP-4 prediction and comparison with experimental data of Standard Problem 5, the prediction of test S-02-8 in the semiscale Mod-1 experimental program. The semiscale system is an electrically heated experiment designed to produce data on system performance typical of PWR thermal-hydraulic behavior. The RELAP-4 program used for these analyses is a digital computer program developed to predict the thermal-hydraulic behavior of experimental systems, water-cooled nuclear reactors subjected to postulated transients, and so on. Sufficient experience has been gained with the semiscale break configuration and the critical flow models in RELAP-4 to accurately predict the break flow and hence the overall system depressurization.

A large discrepancy existed among the measured heater rod temperature data as well as between these data and predicted values. Several potential causes for these differences were considered, and several posttest analyses were performed to evaluate the discrepancies. *Energy Incorporated*

Quad Cities Nuclear Power Station Unit 1 Following Cycle 2

NP-214 Final Report (RP130)

This report is the first of a pair of compilations of reactor power distribution data coming from measurement campaigns at operating power reactors. The purpose of the project is to provide reference quality power distribution information for use in the qualification of reactor core analysis methods. The measurements described were performed at the Quad Cities-1 BWR, owned and operated by Commonwealth Edison Co.

This work is part of the EPRI Reactor Core Performance Program. The objective of this program is to provide for the development and application of computational capabilities used for assessing nuclear reactor core performance characteristics. One particular goal is concerned with the neutronic and thermal-hydraulic analysis required for effective operational evaluations. The results of this project will provide part of the data base against which the various reactor core simulator codes can be qualified. *General Electric Co.*

Evaluation of Fuel Rod Performance in Maine Yankee Core 1

NP-218 Final Report (RP586-1)

This final report presents the results of a comprehensive performance evaluation of Maine Yankee Core 1 fuel prompted by observations of coolant iodine activity increases during Cycle 1.

The program was initiated after the July 1974 shutdown and included a poolside fuel inspection and a hot cell examination of representative fuel rods. The major objective of the overall program was to determine the primary cause of clad perforation. The opportunity was also afforded to obtain fuel rod performance data for evaluating fuel behavior codes. *Combustion Engineering, Inc.*

Use of Plutonium Fuel in BWRs: Destructive Examination of PuO_2—UO_2 Fuel Rods Irradiated in Big Rock Point to 30,000 MWd/t

NP-223 Final Report (2 Vol.) (RP72-2)

This is a report of the destructive examination of three mixed-oxide fuel rods irradiated to a peak burnup of approximately 25,000 MWd/t.

The examinations performed include pulsed eddy current inspection for cladding flaws, rod internal fission-gas collection and analysis, isotopic and burnup analyses, metallography of the fuel and cladding, and microprobe examination for migration of plutonium and fission products. Two of the fuel rods examined contained annular fuel pellets. The third fuel rod contained solid fuel pellets. The original enrichments for the three rods varied from 1.22 to 5.53% Pu/(Pu+U). *General Electric Co.*

Core Design and Operating Data for Cycles 1 and 2 of Quad Cities-1

NP-240 Topical Report (RP497-1)

This report contains the design and operating data needed to define the fuel characteristics and reactor operation characteristics for Cycle 1 and Cycle 2 of the Quad Cities-1 reactor. The purpose is to provide reference quality data for use in the qualification of reactor core analysis methods and to provide the basis for the assessment of the irradiation environment of the plutonium recycle assemblies present.

The design data include fuel assembly description, core component arrangements, control rod descriptions, and core loading patterns. Hydraulic characteristics of the assemblies and the inlet orifices are also provided. Operating data are compiled for 16 steady-state points during Cycle 1 and for 13 during Cycle 2. Each state point includes core average exposure, thermal power, pressure, flux, inlet subcooling, control configuration, and axial in-core detector readings. In addition, benchmark cold critical data are specified. *General Electric Co.*

Assessment of Industry Valve Problems

NP-241 Final Report (RP521-1)

The failure of valves to function as designed has had a significant impact on nuclear plant availability. This report recommends courses of action to be taken to correct specific problems identified in an engineering review of valves and associated equipment currently installed in commercially operating nuclear generating stations.

The report includes specific recommendations to the utility industry on obtaining acceptable valve functional performance and maintenance burden while selecting, specifying, and purchasing valves for nuclear power plant applications.

Recommendations are made for further EPRI-funded research to improve valve designs in regard to improved seat leakage, stem seals, and body-to-bonnet seals. *MPR Associates, Inc.*

Evaluated Neutron Cross Sections for Zirconium and Hafnium

NP-250 Final Report (RP343-1)

This report presents evaluations of neutron cross sections of zirconium and hafnium based on available experimental data supplemented by earlier theoretical nuclear model analyses. The evaluations include thermal cross sections and resolved resonance parameters for the naturally occurring isotopes of zirconium and hafnium. Above the resonance range, elemental point cross sections and secondary neutron energy and angular distributions are provided. *Science Applications, Inc.*

Comparison of Finite Element and Influence Function Methods for Three-dimensional Elastic Analysis of BWR Feedwater Nozzle Cracks

NP-261 Key Phase Report (RP498 and RP700)

This report compares the finite element (FE) and influence function (IF) methods for a three-dimensional elastic analysis of postulated circular-shaped surface cracks in the feedwater nozzle of a typical BWR. The complex nature of the stress gradients and the geometry of the feedwater nozzle region require that accurate numeric methods be employed to calculate stress intensity factors used in fracture mechanics–based fatigue and brittle failure analysis. Currently employed nozzle flaw evaluation methods, as in Section XI of the ASME Boiler and Pressure Vessel Code, are limited to simple geometries and linear gradients of stress.

The FE method is incorporated in a direct manner. The nozzle and crack geometry and the complex loading are included in the simulation model. The IF method is used to compute stress intensity factors only when the uncracked stress field (that is, the stress in the uncracked solid at the locus of the crack) has been computed previously. The IF method utilizes elastic superposition to evaluate correctly the disturbance of this uncracked stress field caused by the crack.

Both methods are described in detail and are applied to several test cases chosen for their similarity to the nozzle crack problem and for the availability of an accurate published result from some recognized third solution method. The results given summarize the accuracy and the direct computer costs of the two methods for each of the selected test cases. *Failure Analysis Associates*

ATWS: A Reappraisal; Part II, Evaluation of Societal Risks Due to Reactor Protection System Failure. Vol. 3, PWR Risk Analysis

NP-265 Key Phase Report (RP767)

This is the third volume of Part II in a series of studies examining the basis for the problem of anticipated transients without scram (ATWS). Part II is an evaluation of societal risks due to RPS failure based on more current data and methodology than used in WASH-1270. This volume examines and documents the potential contribution to societal risk due to ATWS in the PWR. Volumes 1 and 2 described a similar analysis for the BWR.

Risk studies of this type yield information on whether a particular component, subsystem, or system should perhaps be redesigned or backfitted so as to increase its reliability. The Reactor Safety Study (WASH-1400) calculated the PWR ATWS potential risk at 0.3% of the total potential risk. An early reevaluation of PWR failure data implied that it should be increased to 1.5%. However, a more detailed analysis showed that PWRs comprise two distinct statistical populations as far as single rod failure probability is concerned and that the PWR ATWS potential risk should increase only to 0.5% of the total risk. *Science Applications, Inc.*

Separated Flow Model of Two-Phase Flow

NP-275 Interim Report (RP443)

This report describes the status of work in progress at Dartmouth College on the Separated Flow Model of Two-Phase Flow. It reviews the general framework of equations and emphasizes the need for evaluating the usefulness of this formulation when it is applied to relatively simple flow regimes.

The applications chosen for testing the theory are: "Flashing, Including Critical Flow" and "Flow of Bubbles, Suspended in Water, Through Nozzles." Preliminary results and plans for further experiments are described. *Dartmouth College*

Failure Analysis and Failure Prevention in Electric Power Systems

NP-280 Final Report (RP217-1)

This report describes new methods developed to better quantify and increase the reliability, safety, and availability of electric power plants. An improved computerized data base of malfunctions in nuclear power plants combined with detailed metallurgical and mechanical failure analyses have enabled identification of present and potential problem areas.

Significant advances in the accuracy and speed of structural analysis have been made through application of the boundary integral equation and influence function methods of stress and fracture mechanics analysis. The currently specified flaw evaluation procedures of the ASME Boiler and Pressure Vessel Code have been computerized, and results obtained from these procedures for evaluation of specific in-service inspection indications have been compared with results obtained with the improved methods.

Other procedures have been developed to describe and analyze the statistical variations in materials properties and component loading, as well as uncertainties in flaw size that might be passed by quality assurance systems. Improved failure prevention strategies have been formulated by combining probabilistic fracture mechanics and cost optimization techniques. *Failure Analysis Associates*

Cold Leg Emergency Core Coolant Flow Oscillations

NP-282 Topical Report (RP347-1)

The behavior of the emergency core coolant liquid injected into the cold legs of a PWR is of interest for analyzing processes that may occur during a postulated loss-of-coolant accident. During the later stages of blowdown and during refill of the lower plenum and reflood of the core, this liquid can interact with the steam flowing in the cold legs.

In the work described, flow and pressure oscillations were analyzed and investigated experimentally in scale models of PWR cold legs. The analysis has reasonable predicted data obtained in experimental cold leg models varying in (diameter) scale from 1/20 to 1/3, at subcooling temperatures from 10°F to 200°F, at injection angles from 45° to 90°, at downstream lengths from $L_d/D = 15$ to 120, at system pressures from 1 to 4 atm with various boundary conditions, and over a significant range of steam and water flow rates.

The analysis is able, in most cases, to predict the general features of the oscillatory behavior, such as the presence or absence of flow oscillations and the oscillatory frequencies. It fails, in some cases, to predict specific oscillatory characteristics such as pressure amplitudes or the trend of frequency as a function of water flow rate. The broad confirmation of this separate-region analysis suggests that it may be a useful component of future models of the interacting regions of a PWR. *Creare Inc.*

A Computer-oriented Approach to Fault Tree Construction

NP-288 Topical Report 1 (RP297-1)

This report describes a methodology for systematically constructing fault trees for general complex systems via the computer program CAT. Representing component behavior by decision tables allows the modeling of components with various combinations of electrical, fluid, and mechanical inputs and outputs. Each component can have multiple internal failure mechanisms that combine with the input states to produce appropriate output states. This approach allows the modeling of hardware as well as human actions and interactions. Techniques have been developed for compacting such tables to a minimal size.

The report describes a procedure for constructing and editing fault trees, either manually or by computer. The techniques employed result in a complete fault tree, in standard form, suitable for analysis by current computer codes. Methods of describing the system, defining boundary conditions, and specifying complex TOP events are developed in order to set up the initial configuration for which the fault tree is to be constructed. *University of California at Los Angeles*

Documentation of Utility Experience With Process Computers in Power Plants

NP-290 Technical Compendium (RP618)

As part of a project to document the experience that utilities have had with process computers in power plants, technical descriptions were obtained for the computer installations at 334 fossil and nuclear generation plants in 91 utility systems throughout the U.S. and Puerto Rico. These plants all had a generating capacity of 100-MWe or greater.

The compendium should serve as a catalyst for the exchange of information and experience between utilities that have similar process computer installations. To facilitate the use of this document, cross references are provided by system supplier, utility, power plant type, computer vendor, significant applications, and significant modification. *Macro Corp.*

Human Factors Review of Nuclear Power Plant Control Room Design

NP-309-SY Summary Report (RP501)

Human factors engineering is an interdisciplinary specialty concerned with influencing the design of equipment systems, facilities, and operational environments to promote safe, efficient, and reliable operator performance. The human factors aspects of five representative nuclear power plant control rooms were evaluated by such methods as a checklist-guided observation system, structured interviews with operators and trainers, direct observations of operator behavior, task analysis and procedure evaluation, and historical error analysis. The human factors aspects of design practices are illustrated, and many improvements in current practices are suggested. The study recommends that a detailed set of applicable human factors standards be developed to stimulate a uniform and systematic concern for human factors in design considerations. *Lockheed Missiles & Space Company, Inc.*

Determination of Nondestructive Inspection Reliability Using Field or Production Data

NP-315 Technical Report 8 (RP700-1)

A new method uses field or production data rather than specimen data to estimate the probability of the rejection of a part containing an imperfection of a given size, and to estimate the dependence of this probability on the nondestructive inspection (NDI) level or levels. Imperfection response features used to make the accept/reject decision are identified for the inspection processes. Estimates of the correlations between the NDI signal characteristics and the relative size and severity of the imperfection are based on destructive examination of material units containing selected imperfection response amplitudes. This method has a distinct advantage over using flawed specimens: in addition to possible cost savings, the uncertainty of fabricated imperfections (created to represent those encountered in practice) does not have to be taken into account. *Failure Analysis Associates*

ELECTRIC POWER RESEARCH INSTITUTE
Post Office Box 10412, Palo Alto, California 94303

NONPROFIT ORGANIZATION
U.S. POSTAGE
PAID
PALO ALTO, CALIFORNIA
PERMIT NUMBER 281

ADDRESS CORRECTION REQUESTED

EPRI

March 1977