Storing Nuclear Waste

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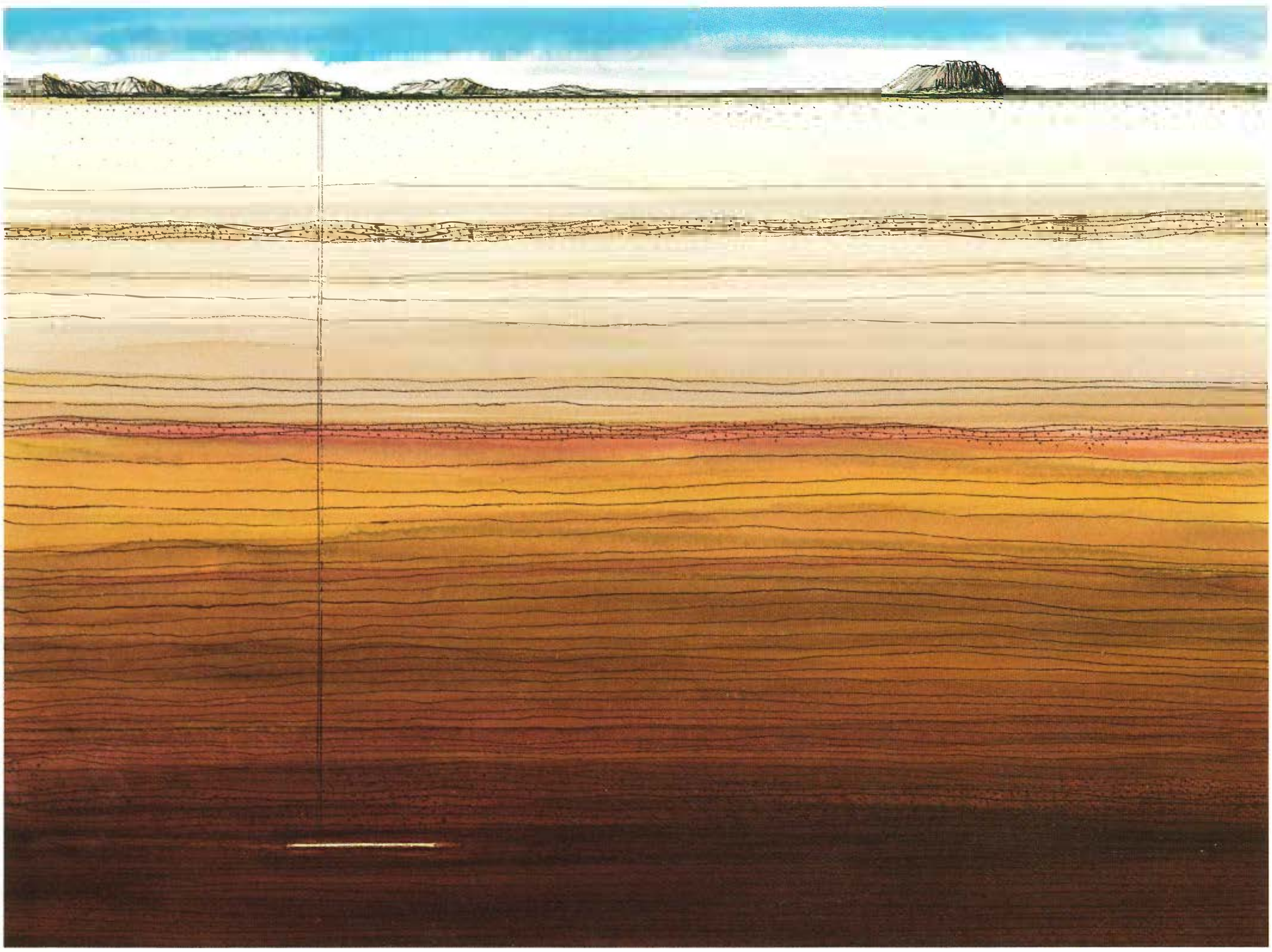

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Cover: Distance is one of many natural and engineered barriers separating the human environment from stored radioactive waste.

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R&D STATUS REPORTS

DEPARTMENTS

Closing the Nuclear Fuel Cycle: The Role of Radioactive Waste Disposal

The demonstration of safe and economic disposal of radioactive waste from reprocessing spent fuel from civilian power plants is starting to show progress. Such progress is urgently needed to eliminate one of the most serious public concerns about nuclear power. In addition, the resolution of safeguards, reprocessing, and radwaste criteria and procedures (which is also the responsibility of the federal government) is needed to permit the most efficient overall use of our uranium energy resources.

Radioactive waste from the reprocessing of spent fuel can be compacted to a small volume, melted with glass frit, and cast into compact "logs" in heavy steel canisters for eventual disposal deep underground. The glass logs provide high integrity against dispersal or leaching of radioactivity. After a few hundred years, the remaining radioactivity will be less than that present in nature as uranium and radium in some underground locations. By proper selection of locations, the likelihood of hazard to the biosphere from the final disposal can be made smaller than the hazards from natural radioactivity.

A production-scale disposal plant using this approach has been completed and is scheduled to begin operation later this year near Marcoule, France. Similar plants are either under construction or planned in the United Kingdom, Germany, Belgium, and Holland.

In the United States, nuclear waste management budgets and priorities have been increased. The responsibility for waste management technology is centralized in ERDA (Division of Nuclear Fuel Cycle and Production). Pilot demonstrations are scheduled from 1978 to 1980, and a federal waste repository is scheduled to receive commercial high-level waste by 1985. Both the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency are pursuing high-priority programs to develop criteria for the licensing and regulation of commercial waste management facilities and operations.

Despite these orderly and seemingly adequate plans, the lack of either pilot- or full-scale demonstration of safe waste disposal, both high-level and low-level, remains one of the most troublesome and frustrating areas for commercial nuclear power. Utilities are criticized for the lack of convincing progress in demonstration of safe and economic disposal methods. Yet the development, demonstration, and the environmental and legal aspects of radioactive waste disposal are under federal control—and are also subject to state overview. Legislation passed in California and pending in other states, for example, specifies the demonstration of safe disposal as a prerequisite to further nuclear plant commitments.

Much of the basis for public concern stems from past military waste management practices, which seem less than ideal in the light of current environmental standards.

The volume of military radwaste in the U.S. is more than 600 times larger than that of high-level waste from civilian reactors, which will not reach 10% of the military waste volume until well into the 1990s and possibly only after the year 2000. This led the AEC (predecessor to ERDA) to defer decisions on specific processes and regulations for final disposal of civilian radwaste until the 1990s—a policy that has now been reversed by ERDA and NRC.

The application of civilian radwaste solidification and disposal standards to military waste is being studied but is not as yet planned or budgeted because of the large volume and the less tractable chemical form of military waste and the resultant high cost of its treatment (many billions of dollars). The upcoming hearings on military waste disposal are likely to highlight the questions of the credibility of timely and effective federal actions in this area. This situation inevitably reflects negatively on the public acceptance of plans for civilian waste disposal, even though the civilian process waste is more conveniently concentrated and disposed of. It is therefore important that the media and the public become better informed and able to distinguish between the military and the civilian waste disposal issues.

A series of documents and public hearings on both the civilian and the military waste disposal programs is scheduled for 1976–1977. The GESMO hearings on the use of plutonium will also cover some of the related issues in the areas of safeguards and reprocessing.

The article by Gary Dau and Robert Williams (page 6) provides an excellent overview of the status of disposal of high-level waste and shows there is good assurance that safe and economic methods are technically available and, with the further step of demonstration, will be worthy of public acceptance. The most important additional effort required, in my opinion, is a risk assessment study, similar to the Rasmussen report on reactor hazards. This can provide the technical community and the public with a good basis for understanding that the risks can be made extremely small relative to natural and other man-made hazards. If the federal scale-up, demonstration, and regulatory efforts are kept on schedule, proven waste management systems should be available for large-scale use by the mid-1980s, when the volume of waste reprocessed from spent power reactor fuel can first become significant.

Ed Zebroski

E. L. Zebroski, Director
Systems and Materials Department
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New. Sometimes it is a small component. Sometimes it is an entire technology. Always it begins with a way of thinking, a different ordering of data or of concepts so that new insight is possible. But in reviewing applied research, we frequently concentrate so much on the tangible results that we fail to appreciate the abstract processes that lie behind them. With this observation in mind the three feature articles in the following pages may be seen to share an added dimension.

▫ "Secure Storage of Radioactive Waste" (page 6) is a research challenge for which the concept and the reasoning are especially important because they form the basis for a general acceptance of the technology and practice that will follow from them. Gary Dau and Robert Williams write at a time of transition between concept and practice. In so doing, they illuminate both the technical issues requiring resolution and the experimental research results that describe a system likely to be built and operated to serve the nuclear electric power community.

Gary Dau came to nuclear waste management research with a background in the nondestructive testing and monitoring of components subject to radiation, thermal, and pressure stress.

After graduating in mechanical engineering from the University of Idaho in 1961, Dau turned to nuclear engineering and earned his PhD at the University of Arizona in 1965. Since then he has been with Battelle, Pacific Northwest Laboratories as a research scientist and manager in electromagnetic testing, infrared and thermal techniques, ultrasonics, acoustic emission, spectroscopy, radiography, eddy current testing, and acoustic holography. Dau also helped develop new technology to meet ASME code provisions for in-service inspection of nuclear power plant components.

A senior R&D manager since 1968, Dau took responsibility in 1974 for establishing a program management function to coordinate the specialized work of several R&D departments in Battelle-Northwest's radioactive waste disposal program. From February 1975 until July 1976 he was on loan to EPRI's Nuclear Power Division, where he held management responsibility for projects in both nondestructive testing and waste management.


Dau

▫ Robert Williams is a Stanford University graduate in chemical engineering (1961) who immediately turned to the power field—first as engineering officer on a navy destroyer for three years, then as a development engineer with General Electric Company's Nuclear Energy Division. For six years he worked in advanced BWR design development, where his responsibilities included heat transfer studies, computer modeling and cost evaluation, and probabilistic risk assessment. He also completed GE's advanced mechanics course in mechanical engineering, the equivalent of a master's degree.

In 1970 Williams joined the GE marketing staff with responsibilities in fuels and product planning. By 1974 he had thus been closely associated with development of the BWR No. 5 and No. 6 product lines introduced by GE. He had also earned an MBA degree in finance at the University of Santa Clara and had become a program manager for GE's strategic planning of future energy systems.

Increasingly interested in the long-range needs of nuclear power technology, Williams came to EPRI in January 1975, where he is now a program engineer in the Nuclear Systems and Materials Department.

▫ Because of rapidly rising capital costs, the research investment exerting greatest leverage—especially in the near term—is frequently the one that will improve the reliability of existing plants. But the best prospects aren't necessarily obvious, according to Donald Anson, so "Defining Communication Needs for Power Plant Reliability Research" (page 15) becomes

Williams

Anson

Johnson

the first task of economical research planning. In line with his background, Anson's article focuses especially on fossil-fired plants.

After starting with five years of engineering apprenticeship, Anson graduated in mechanical engineering in 1949 from University College at Southampton, England, and then, specializing in the combustion of liquid fuel sprays, earned a PhD in 1951 from London's Queen Mary College. After a brief period of professional work in solid fuels and geothermal resource assessment—the latter in New Zealand—he joined Shell Research Ltd. in Thornton, Cheshire. There, he headed research activity in oil combustion, including the corrosion and pollution effects of its products.

In 1959 Anson began work with the British Central Electricity Generating Board (CEGB), where he established a combustion laboratory, gained responsibility for combustion research, and ultimately came to head the chemical engineering section. His CEGB duties also included supervising work in nuclear coolant gas composition control.

Although his office was at one of the CEGB headquarters laboratories (Marchwood), Anson worked closely with regional research facilities whose activities involved cooperation with plant personnel throughout the CEGB system in England and Wales. The lessons of that experience came with him when he joined EPRI on loan in December 1974. They influence his work—and his authorship—today as acting manager of EPRI's new Fossil Plant Performance and Reliability Program.

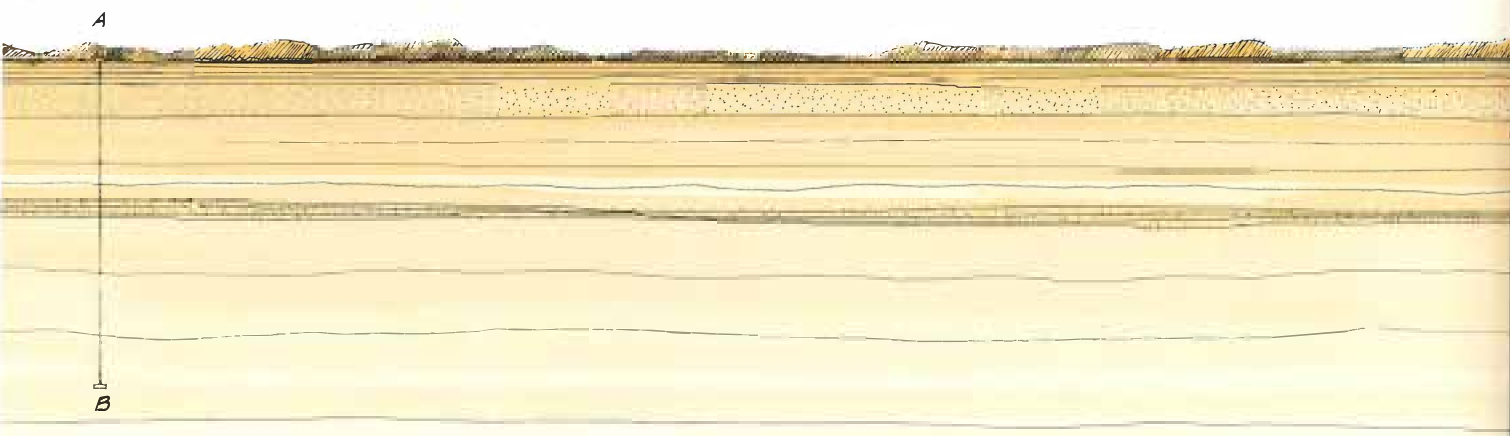
□ Specific research toward a specific objective marks Walter Johnson's work in "Improving Gas Dielectric Performance for Substation Design" (page 20). Johnson has been with Potomac Electric Power Co. (PEPCO) since he graduated in electrical engineering from Duke University in 1960. For most of the past 16 years he has specialized in substations, their equipment, controls, and construction.

Acting under the dual pressures of a shortage of available urban land and stringent governmental esthetic standards (especially in metropolitan Washington, D.C.), PEPCO was among the first U.S. electric utilities to adopt gas insulation as a means of smaller, more attractive substation packaging. Johnson's experience in that effort, as principal engineer for substations, led him to join EPRI's Transmission and Distribution Division on loan in September 1975. He is now a staff member of the AC and DC Substations Program, leading an important segment of EPRI research.

Secure Storage of Radioactive Waste

by Gary Dau and Robert Williams

Integrally bound in massive glass billets cast in stainless steel casks deposited in vaults cut deep in stable geologic formations, high-level nuclear waste can now be stored away from the human environment, to end a long-standing public concern. ▫ An EPRI state-of-the-art feature



As public debate continues over the need for and the safety of nuclear power as a major energy source for electrifying our third century, the management of radioactive waste materials remains a key concern.

Gary Dau, a senior R&D manager at Battelle, Pacific Northwest Laboratories, was on loan to EPRI for 17 months through July 1976 as a project engineer in the Nuclear Systems and Materials Department, Nuclear Power Division. Robert Williams is a program engineer in the same department.

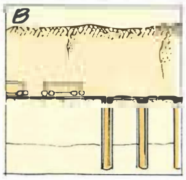
How dangerous are nuclear waste products? How much material will be generated in the years ahead, and how long will it remain radioactive? Where will we store it, and how will we transport it safely to those storage sites?

These are questions that concerned citizens, legislators, and regulators are asking as they consider energy alternatives for the future. And some allege that solutions to these problems are not feasible or available.

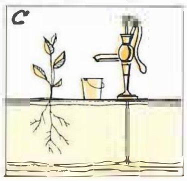
The fact is, however, that the technology for disposing safely of nuclear waste material is, indeed, already available—and by several processes.

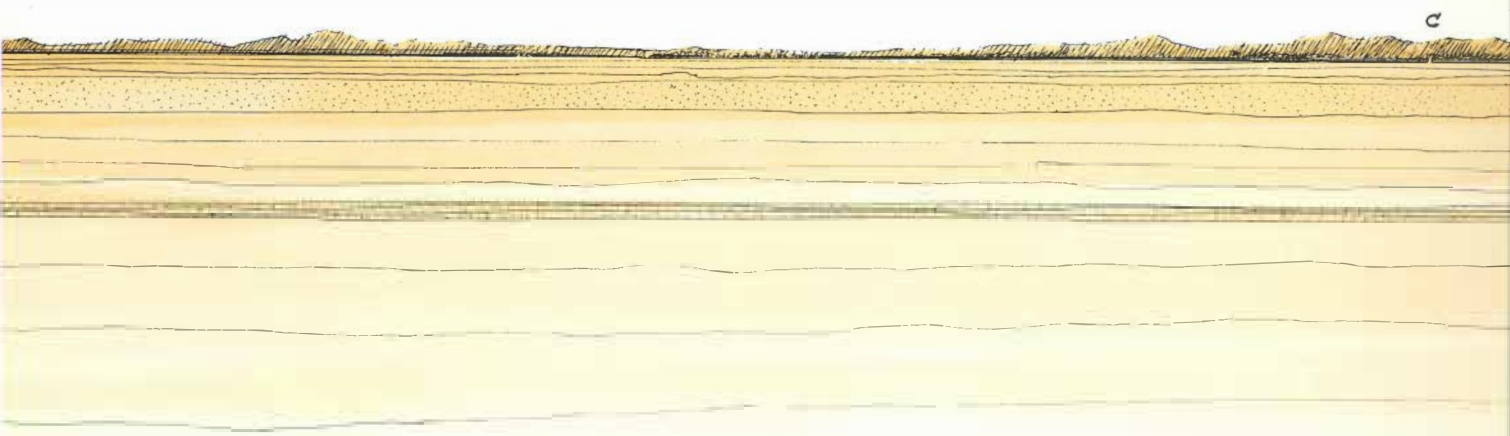
The federal government and the nuclear power industry have sponsored considerable research and development on nuclear waste management. The technical feasibility of several alternative processes has been adequately demonstrated on at least a pilot scale for each required step, from the discharge of spent reactor fuel to the disposal of radioactive waste in ter-

There are numerous serial barriers that will be erected between nuclear waste storage and the human environment, starting with distance—up to a mile vertically between the federal repository (**A**) and the storage vault (**B**), and about 10 miles between the repository and the nearest habitation (**C**).



It would require a geologic disturbance of exceptional severity—and very low probability—for water to reach the burial site. The water would have to penetrate half an inch of stainless steel, which has a very high corrosion resistance. The waste-bearing glass within the steel canister would have to dissolve, although it has an extremely low leach rate. Then the high-level waste materials would have to traverse the soil column, which has been shown to be a very effective filter. Thereafter the waste would have to find its way to an aquifer, in which it would be diluted. Any radioactive materials passing through all these barriers would be below the threshold of measurability.





minal storage. Some or all of these steps have also been demonstrated in actual operation in France, Germany, and the United Kingdom. The technology has reached the point where full-scale application is practical, and additional plants are planned in Belgium, the Netherlands, Italy, Spain, and Sweden.

The most promising route

Among the several processes available for nuclear waste disposal, the most attractive alternative is a system that converts high-level liquid waste to a solid and immobilizes it in glass. Ultimate disposal, retrievably or permanently, would be in vaults cut into deep, dry, stable geologic structures such as granite, desert soil, or salt. This method is attractive both because the technology is available today and because it would require less time than other methods to carry it to commercial scale.

The authors have reviewed available technology and have selected what appears to be the best of several alternatives at each step in the waste-handling process, as a technique for presenting the current status of the technology to the public and the industry.* The process consists of the following sequence.

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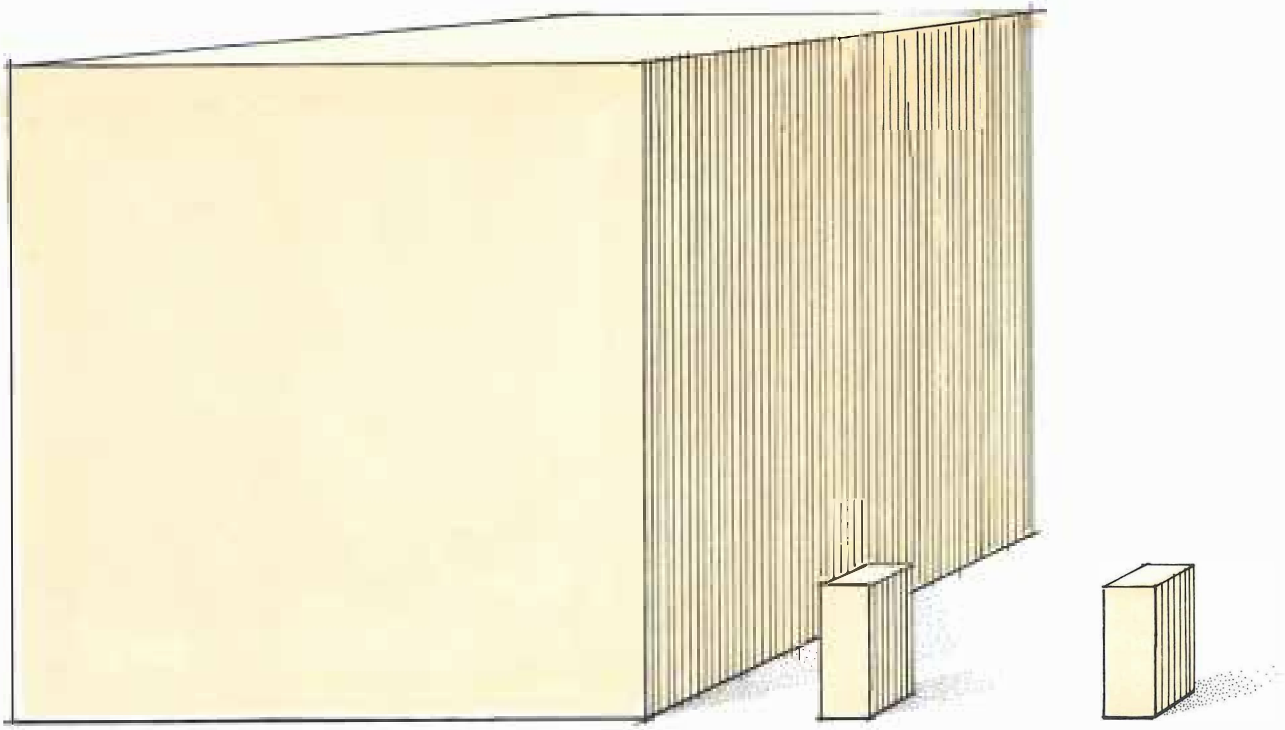
*EPRI SR-44 *The Status of Commercial Nuclear High-Level Waste Disposal.* This study contains the details and references on which this article is based.

VOLUME OF NUCLEAR WASTE PRODUCED FROM NATURAL URANIUM



1. 1,823,000 liters of uranium ore must be mined to produce 1 metric ton of nuclear fuel.

2. The metric ton of ore yields 91 liters of uranium dioxide fuel before it is sealed in Zircaloy rods to be loaded into a reactor.

3. The spent fuel is stored in a pool to permit radioactive decay of short-lived fission products.

□ Fuel reprocessing—isolating the waste from nuclear fuel by solvent extraction, based on worldwide reprocessing experience totaling more than 380 plant-years†

□ High-level liquid waste storage—short-term storage in a double-walled, stainless steel tank set in a concrete vault

□ Two-step solidification—conversion of the liquid to dry oxide granules (calcine), then vitrification (glassification) of the calcine to a highly insoluble glass (borosilicate glass, about the same composition as Pyrex) within the stainless steel canister to be used for ultimate disposal

□ Transportation and final disposal—shipment by rail or truck (in casks like those used to transport spent fuel) to a government-owned depository where the canisters would be stored and sealed in vaults cut into stable geologic formations at depths greater than 1000 meters

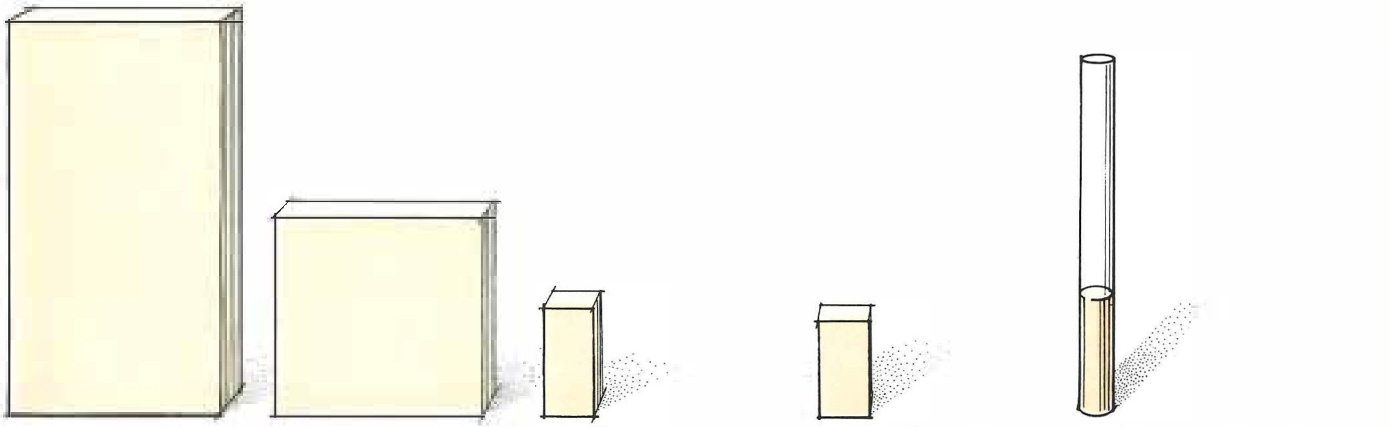
□ Decontamination of fuel cladding and hardware residue by treatment with hydrogen fluoride at 600°C and then with aqueous hydrogen fluoride solution, followed by consolidation into ingots for storage or recycling

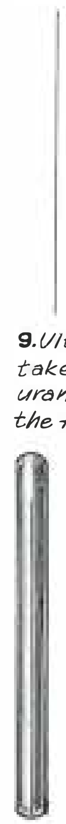
Origin, nature of waste

When a chain reaction takes place in a reactor, each atom of uranium-235 that fissions yields not only heat energy and one or two neutrons but also two "fission fragments" (new atoms of some 35 other elements, including such common ones as silver, tin, zinc, iodine, bromine, arsenic, and antimony, as well as a number of rare ones). Some of the new atoms from each fission are highly radioactive isotopes of those elements.

As the fuel in the reactor fissions and generates heat for electric power production, the fission fragments accumulate and gradually dampen the chain reaction by competing with uranium atoms to capture neutrons. It therefore becomes necessary to refuel the reactor, usually replacing one-third of the fuel per year. However, the discharged

†This includes 256 plant operating years in the U.S. and 133 plant-years in eight other countries. (For documentation, see EPRI report SR-44.)





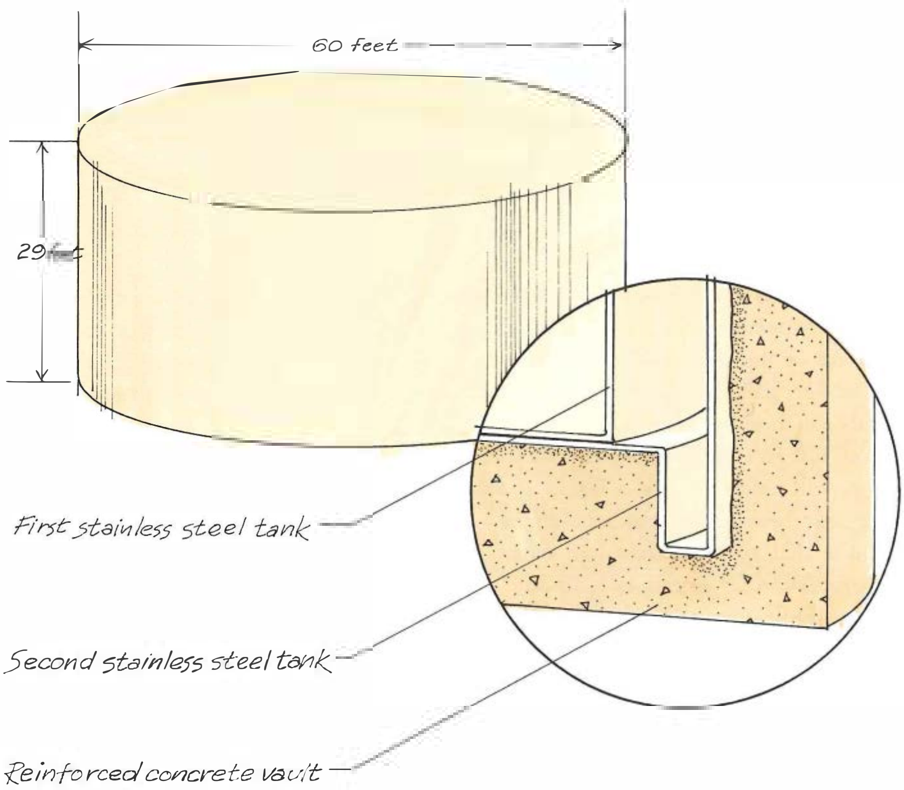
fuel contains substantial energy value in the unfissioned uranium-235 and in the plutonium bred from uranium-238, making it desirable to reclaim and recycle this material for both resource conservation and economy. In fuel reprocessing, the residual uranium-235 and plutonium are separated by solvent extraction from the fission products, of which 99% come off as a concentrated acidic aqueous stream. This is where high-level waste (HLW), as such, is born.

Each metric ton of uranium processed results in about 1100 gallons of liquid HLW. Based on a recent projection of the amount of nuclear capacity that will be installed by the end of the century (160,000 MWe by 1985; 625,000 MWe by 2000), the total *commercial* liquid HLW—excluding military waste—expected to be produced by the end of the year 2000 is only about 29 million gallons. However, even this total, which is equivalent to only 10 tanks 100 feet in diameter and 50 feet deep, will never exist as a liquid at any one time because current regulations require that no more than five years' accumulation be stored as a liquid. The solidification and glassification processes expected to be used will reduce the liquid volume by about eight times. So, even if the total amount of glass were to be piled evenly on a football field at one time, it would reach a height of less than 13 feet. Actually, however, the glass will be contained in steel canisters spaced at intervals to permit heat dissipation.

Liquid storage

The tanks to be used at commercial reprocessing plants to store liquid HLW will be a far cry from the first tanks built to store military radioactive waste at Hanford, Washington, in the days of the Manhattan Project. Some of those (single-walled, mild steel tanks buried in the desert) are now more than 30 years old; a few have sprung leaks, thus achieving notoriety.

By contrast, a policy of double containment for HLW was adopted by AEC at its Savannah River plant. This practice has been very successful in averting Hanford-type leaks and has served as the basis for commercial HLW storage practice. For example, the HLW tank built at the Barnwell, South Carolina, commercial reprocessing plant can hold the waste liquid from the reprocessing of 2000 metric tons of fuel after preliminary in-tank concentration. Built of 304L-type stainless steel, each consists of an inner tank, 54 feet in diameter and 20 feet in height, which is contained by a second stainless steel tank, which in turn is inside a reinforced concrete vault 4 feet thick, set 10 feet underground. The bottom of the inner tank and the lower 8 feet of its wall are half an inch thick. The concrete vault, 60 feet in diameter and 26 feet in height, has a floor 4 feet thick and a sump instrumented to detect any leak immediately. The sump also permits checking the integrity of the outer steel tank. The tank is equipped with an elaborate cooling system and an agitator system to continuously scour the bottom and lower corners of the inner tank, to prevent the contents from settling. Several wells and a cooling pond provide a backup supply of cooling water.



Double-containment approach to storing liquid waste is in reality a triple barrier between the waste and the environment: an inner stainless steel tank in an outer stainless steel tank, which in turn is set in a concrete vault.

Solidification

The liquid waste is solidified in two steps—calcination and vitrification—to further reduce the waste volume and to achieve a form suitable for ultimate disposal.

Calcination Present NRC regulations require that liquid waste be solidified within five years after reprocessing and be shipped to a federal depository within five years thereafter. The regulations are not specific about the form of the solid, requiring only that it be thermally, chemically, and radiolytically stable and inert.

Calcine has been recognized as one solid form for waste that meets those general requirements. A calcine is the product that results when liquid inorganic materials are heated to temperatures in the 300–900°C range, which drives off water and NO_x gases and leaves dry oxide granules or powder. This calcine is more stable than liquid, less mobile, and occupies only one-eighth as much space.

Considerable experience has been accumulated with the calcination process since AEC began its development in 1955. A pilot-scale waste calcining plant at the Idaho Nuclear Engineering Laboratory has operated successfully since 1963, using a fluidized-bed calcination process; it is now being expanded. More than 2.6 million gallons of liquid HLW have been solidified in the past 14 years.

Two improved calcination processes are also being evaluated: a modified fluidized-bed process and a vertical spray concept. Both have shown they will convert simulated waste to calcine, and both have successfully produced calcine feed for pilot-plant vitrification processes. The spray calciner has also processed radioactive material.

Vitrification Development work on vitrifying HLW has been underway since the mid-1950s and has made great strides in the past decade.

The major difference between a glass and a calcine is that glass is a fused substance, in which each atom of HLW occupies a fixed location that does not change once the glass has solidified. Consequently, the radioactive atoms in the HLW assume the chemical inertness that is a quality of the glass itself. The greater density of the glass compensates for the addition of glass-making materials, leaving the volume of calcine and glass essentially the same.

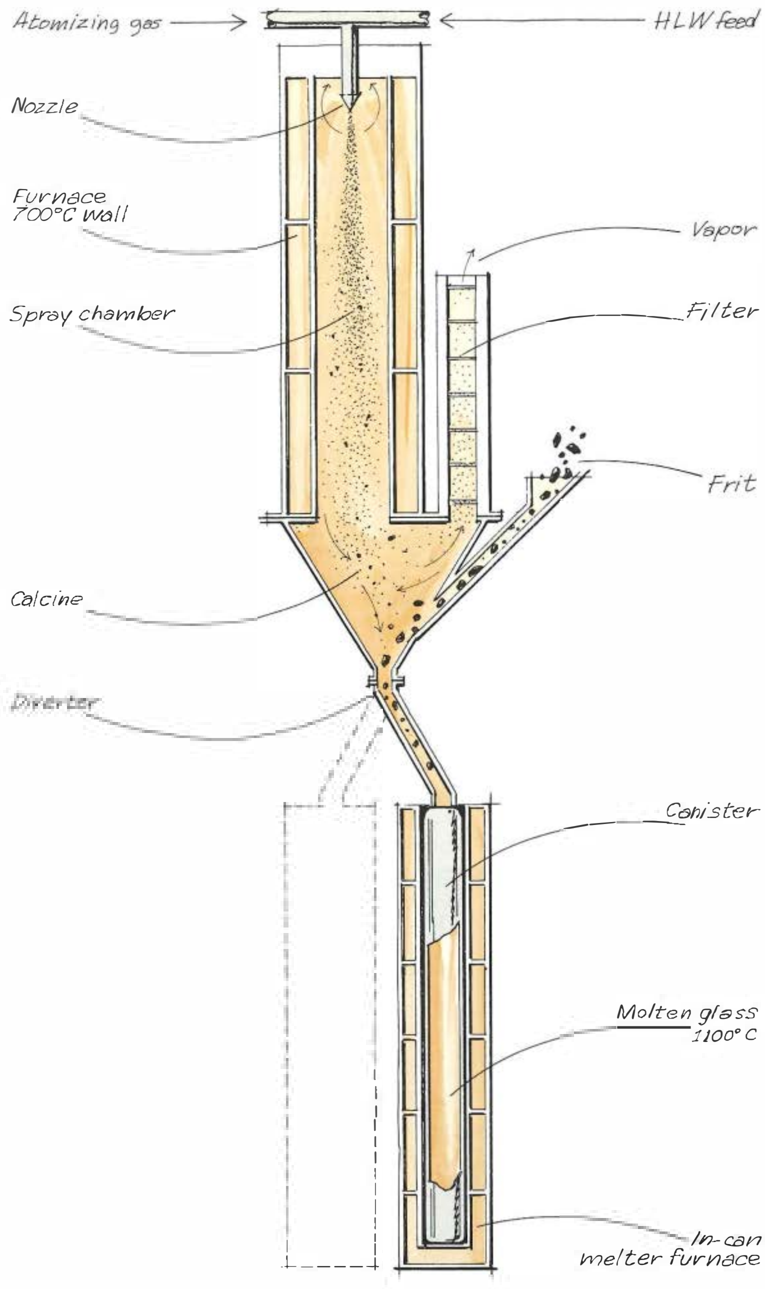
The potential dispersibility of waste in glass if exposed to air, groundwater, or fire is roughly 1000 times less than that of waste in calcine.

Although until fairly recently a two-step process was contemplated (calcination and temporary storage followed by vitrification), the method now being pursued most vigorously is a single-step process for vitrifying calcine *in place* in the canister.

This process starts when the waste is sprayed as a liquid into a heated chamber. The moisture and other volatile materials are driven off. When the material reaches the bottom of the chamber, it is in calcine form. This is loaded into the storage canister, together with glass-making frit (mainly oxides of silicon, boron, and phosphorus), mixed, and heated to 1100°C. As the molten material cools at a controlled rate, it solidifies into a monolithic block and the waste atoms are bound as integral parts of the glass, filling the inside of the canister.

Experience with pilot-scale equipment confirms that no major technological breakthrough is needed before this process can be used in a full-scale plant. Pilot-scale operations with calciners and glass-making equipment have already shown that the throughput required for a commercial-scale plant can be maintained.

Radiation Effects In AEC's prototype waste solidification program, concluded in 1970, the equivalent of the waste from 40 metric tons of fuel was fixed in glass. The effect of radiation on the glass itself over periods of time was studied. To obtain accelerated data on



In single-step conversion, liquid high-level waste is converted to fine powder in the calciner (top), mixed with glass-making frit, and melted (bottom) into a block of glass within the stainless steel canister in which it will be finally stored.

the effects of radioactivity, two canisters were filled with simulated waste containing large amounts of radioactive cerium-144. To date, no significant adverse effects have been found.

More recently, radioactive curium-244 was included in the test procedure to obtain a more rapid simulation of extended radiation exposure. The amount of radioactivity from this source in 5 years produces radiation damage equal to what could be expected from actual HLW during 10,000 years of storage. After a time equivalent to the passage of 2000 years, the glass continues to exhibit characteristics acceptable for waste disposal.

These results show that glass is indeed a durable and reliable medium in which to immobilize HLW.

The common impression that glass is a highly fragile material may raise some questions about the susceptibility of waste-bearing glass to fracture during mechanical handling. Preliminary data, however, confirm that this is not a concern when using glass cast into large blocks. Glass encased in stainless steel canisters, at one-half and one-sixth scale, was impact-tested at speeds up to 80 miles an hour. The results show that only a small fraction of HLW would be released, with manageable localized consequences similar to a spill from a railroad chemical tank car.

Researcher examines a billet of simulated waste-bearing glass within a 2-foot length of pipe representing the disposal canisters, which are expected to be 10 feet long. This work was done at Battelle, Pacific Northwest Laboratories.

Canisters The final step in fixing radioactive waste takes place in the steel canister in which the calcine is melted with glass frit. The canister is an additional barrier that separates the radioactivity from the environment. To date the government has set no standards to specify size, shape, or material for the canisters. Industry has assumed a cylinder as the shape and 304L stainless as the material. For convenience, dimensions of a height of 10 feet and a diameter of 1 foot have been provisionally assumed—although conceivably the height could vary from 2 to 12 feet and the diameter, from 6 inches to 2 feet.

Transportation

In view of the technical superiority of glass over calcine, it is reasonable to assume that regulations will ultimately stipulate that HLW be converted to glass at the reprocessing site. This would greatly reduce any risk during subsequent transportation.

The transportation phase of waste disposal would consist of hauling canisters of solid waste from the reprocessing plant to a federally owned and operated depository. The canisters would be carried—like fuel assemblies—in specially designed casks aboard either trucks or trains.

Although a cask designed specifically for transporting waste canisters has not yet been fabricated, the basic design would be very similar to the casks used for spent-fuel transport. It would have its own shielding, adequate to limit the radiation exposure of transportation workers and the general public to negligible values.

Final emplacement and risk measures

The canisters eventually will be placed deep underground, in formations that have been stable for millions of years and that are remote from local water tables. The barriers against the movement of radioactivity to the biosphere are (1) emplacement at a distance from means of transport such as groundwater; (2) the integrity of glass and its resistance to leaching by water; (3) the absorption capability of the rock or soil if some leaching should occur. (The possibility of some material reaching the biosphere is obviously subject to analysis for any particular location.)

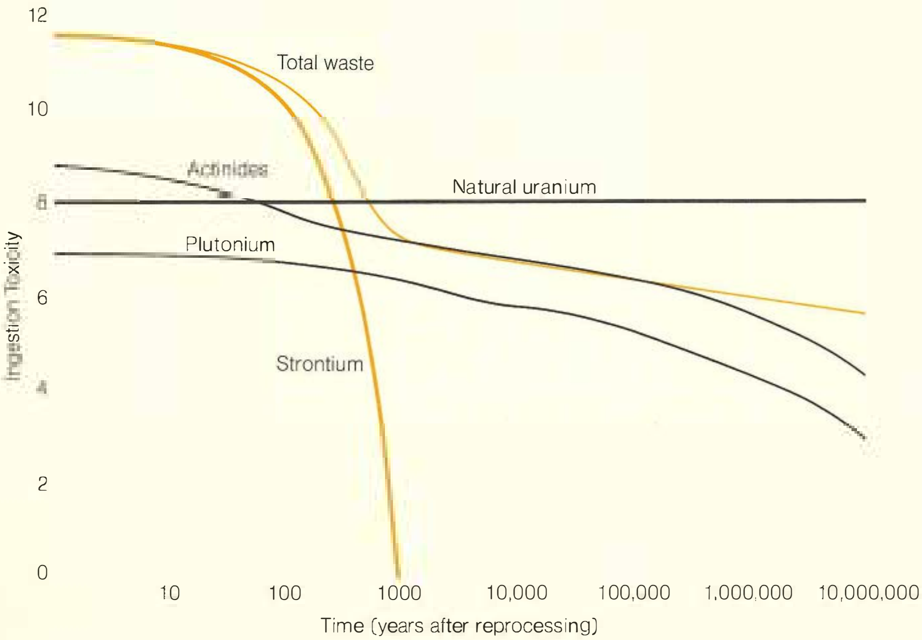
A complete risk analysis (like the Rasmussen report for reactors) has not been performed for transport of HLW, but studies to date suggest that both the near-term and long-term risks from the type of disposal described here can be routinely made very small. The long-term hazard is about the same as that from naturally occurring uranium and radium in the earth. It appears that overall radiological consequences of the total range of conceivable accidents will be several orders of magnitude *below* those arising from the more common, nonradiological kinds of accidents.

The radiation dose to transportation workers and the general public will be a small fraction of the total annual permissible dose.

Other solid wastes from fuel

One other aspect of the handling of reactor waste involves disposal of fuel cladding and hardware associated with the fuel bundle. After reprocessing has been completed, some solid matter (aside from the HLW) remains radioactive and requires proper handling. This includes the end fittings of the fuel assemblies and the empty sections of zirconium tubing (hulls) into which the fuel rods have been sheared to permit dissolving out the fuel. A film containing traces of uranium and

Within a finite period, the hazardous components of nuclear waste decay to a radioactive toxicity level lower than that of the natural uranium from which the waste was derived. The strontium in waste becomes less toxic to humans than natural uranium ore in 450 years; the total waste, including plutonium, becomes less toxic in 500 to 1000 years, depending on fuel history and reprocessing-plant characteristics.



plutonium remains on the inside surfaces of the hulls. An effective decontamination procedure for hulls has been tested recently. It consists of exposing the hulls to gaseous hydrogen fluoride at 600°C, and then treating them in aqueous fluoride. Analysis of fuel cladding treated by this procedure indicates that 99.7% of the residual radioactivity is removed.

Once decontamination is complete, several options are open for further treatment of the high-volume, low-density hulls to reduce volume. One approach is simply to compact the hulls with a mechanical crusher. Another option is consolidation by melting and casting of Zircaloy, stainless steel, and Inconel ingots, or an alloy of all three. The dense, monolithic, corrosion-resistant alloy blocks would be in a stable form for disposal.

Other wastes

Nuclear waste of lower levels of activity than HLW includes wastes and scrap generated in mining and milling uranium and in fabricating fuel rods and low-level wastes from reactor operation.

Normal reactor operation also produces some radioactive waste from the water coolant and from cleaning and decontamination operations in the power plant. Gaseous wastes generated from fission-product gases are separated and stored until their radioactivity has decayed to safe levels. Liquid wastes are concentrated by removing excess moisture and converting the residue to a cementlike solid block, which is then shipped to federally licensed burial sites for disposal.

The reprocessing plant produces low-level liquid wastes in addition to the high-level liquid waste stream and the fuel cladding hulls. These include cleanup, rinsing, and decontamination solutions, which can be treated like the low-level liquid wastes from a reactor. Contaminated wiping rags, protective clothing, hand tools, discarded small components, broken light bulbs, and the like represent no problem technically and can be compacted and packaged for commercial burial at NRC-licensed low-level-waste burial sites.

Criteria for safe disposal

If, as we hope we have shown, the technology for safe and reliable management of nuclear waste material is available and ready for full-scale demonstration, what is causing the delay? The missing link is not one of technology but rather one of criteria, standards, and practice. The basic issues are: (1) What criteria and regulations will define acceptable and safe procedures? (2) Which of the various procedures best meets the regulations in a reliable and economic manner? (3) How can public acceptance be obtained? (4) How can coordination and a sense of urgency be maintained in the complex of government and industry?

In other words, how safe is safe enough?

To provide an objective yardstick by which to set criteria for storage of nuclear waste so that it remains harmless to both present and future generations, industry and government researchers compare the level of radioactivity of stored waste from a given amount of fuel to the radioactivity naturally present in the ore that was mined to obtain that amount of fuel.

Scientists express this comparison in terms of ingestion toxicity, a measure of the volume of water required to dilute stored waste to the maximum concentration that federal standards have set as safe; or, in other words, the maximum amount of radioactive material that can be eaten or drunk with no harm to the individual. For perspective, we note that radioactivity of natural potassium, uranium, and radium have always been a part of the human body and its environment. The "allowable" federal levels are small, relative to the radioactivity of such natural sources.

For example, to obtain 1000 kilograms of 3.2% enriched fuel from a typical ore grade (4 pounds of U_3O_8/t), about 64,000 cubic feet of ore would have to be mined. It can be shown that after only about 450 years, the toxicity of the total stored waste from the original 1000 kilograms of fuel is less than that contained in the ore from which the fuel was obtained. In the long term—many thousands of years—the total radioactivity in the topmost mile of the earth's surface will be *decreased* rather than *increased* by the operation of nuclear reactors!

Thus it can be seen that the highly publicized statements about having to guard deadly materials for half a million years need thorough reevaluation.

At present, there is a three-way "chicken or egg" proposition: (1) Industry cannot prudently commit capital for a full-scale disposal facility until criteria and regulations for ultimate disposal are set; (2) regulations have not been set because some data are not yet available to aid in judging how well technology can perform; (3) the precise direction of R&D is hampered by the lack of final criteria and commercial operating experience. And so continues a frustrating circular argument, with industry awaiting regulations before committing facilities, government awaiting data before setting regulations, and researchers awaiting regulations before being able to produce precisely those data needed.

Now that the technology is available, this circle must be broken and efforts coordinated to achieve an accepted disposal system.

Efforts underway

There is encouraging evidence that the responsible agencies of the government recognize the urgent need for action and are deciding on the technology to be used at each step in the process that constitutes a complete system. A concerted effort to meet this need is now underway within ERDA, NRC, and EPA. Congress has approved ERDA funding of $60 million for fiscal year 1977 (more than the $12 million funding in 1976) and $30 million for military waste management (compared with $19 million in 1976). Congress has also held hearings on civilian waste management. ERDA is working toward adoption of a waste management system, including development of and public comment on a generic environmental statement it expects to issue by mid-1977. This timing would permit work to proceed, culminating in the transfer of high-level waste from commercial reprocessors to federal custody by 1983–1984 and the startup of the first storage depository for commercial nuclear waste by 1984–1985.

Efforts have also been underway overseas to demonstrate a waste management system. In France, an HLW solidification demonstration plant is under construction at Marcoule, scheduled for radioactive operation in mid-1977; it is a scale-up of the PIVER pilot plant that has been operating successfully since 1970. Similarly, by 1978 West Germany is expected to be operating a prototype HLW management system, up to and including storage in a salt dome, where some wastes are already being stored experimentally.

With today's technology and work toward the criteria needed for a nuclear waste management system, the prospects for a successful and convincing full-scale demonstration look brighter. Those concerned about the effective use of our fuel resources recognize that timely demonstration of safe and accepted management of radioactive waste materials is the key to closing the fuel cycle. We expect that the combined efforts of government and industry will provide the means by which nuclear power will remain a safe and viable energy source.

Defining Communication Needs for Power Plant Reliability Research

by Donald Anson

Efficient technical communication isn't automatic. It requires deliberate effort by plant engineers, service engineers, and research specialists. British power industry practice provides an example of how U.S. utilities and EPRI can cooperate in better fault diagnosis and more effective research planning. □ An EPRI program article

When a new power plant of any kind starts up, technical problems may arise. There may be design errors or omissions, incorrect choice of materials, a failure to operate the plant correctly, or faults of manufacture or assembly. (Lengths of ordinary carbon steel have been known to find their way into superheaters, which call for heat-resistant materials!)

Where technological advances are involved, there is also a risk that the underlying data base is in some way inadequate. For instance, as higher operating temperatures are adopted, new corrosion problems often occur.

Most frequently the problem is specific to a particular unit, as with a substandard component. But sometimes it is generic to all units of a given type (design fault), and at other times it is generic to a range of units operating under specific conditions (inadequate data base).

Diagnosing the cause of any such problem is seldom easy, but when it is done with precision a form of solution can be proposed and tested with greater confidence. A logical progression in the process ensures maximum benefit from the experience.

Donald Anson, on loan from the Central Electricity Generating Board in Great Britain, is acting manager of the Fossil Plant Performance and Reliability Program in the Fossil Fuel Power Plants Department of EPRI's Fossil Fuel and Advanced Systems Division.

The practical diagnosis

The utility engineer responsible for plant operation develops a feel for trouble. This is sometimes ascribed to instinct, but it is largely the subconscious application of logic; and when the engineer has had long experience with a particular plant, his judgment becomes highly selective. On new or unfamiliar plants, however, he will be less confident in his diagnosis and, as a consequence, may allow a fault to develop to a critical stage—a costly way of gaining experience.

The operating engineer judges himself largely by his ability to keep the plant in service, and indeed this is the criterion set by most managements. Thus the engineer is concerned largely with results, depends a great deal on experience and judgment, and cannot spare the time to be overly concerned with scientific detail. He is probably able to trace many faults to design, construction, or operating deficiencies. Depending on his ability, he may develop a "gut feeling" about correctives. But he generally is unable to go much further than this. Not only does he lack the time but he cannot be expected to have the specialized knowledge required to analyze many of the problems arising in today's sophisticated plants.

In describing a specific failure, the engineer tends to be vague about the mechanism or even inaccurate in scientific terms—a tube failure in a boiler may be described simply as a burst. This is not enough to get proper scientific attention, which would ensure a correct failure diagnosis. The incident might involve an aerodynamicist (if erosion is contributory), a metallurgist (fracture mechanics), a fuels chemist (external corrosion), a water chemist (internal corrosion), or specialists in other disciplines—most likely a combination of several.

Communicating the diagnosis

Providing a reliable fault diagnosis is the first major difficulty in setting scientists to solve operational problems discovered by engineers. Typically they do not speak the same language, and they may even be unsympathetic to one another's attitudes unless a deliberate effort is made to develop mutual understanding. Basically, however, their roles are complementary, and this fact must be accepted if progress is to be made.

The first stage in scientific investigation is the careful assembly of information on which a hypothesis can be formulated and tested to provide explanations for observed phenomena. The process is time-consuming, but capable eventually of defining with precision the nature of a phenomenon and of changing it in a prescribed manner. Applied to faults, this means that scientific investigation can offer not only correctives but also criteria to ensure that the same kinds of faults do not recur in future designs. At the same time, it must be recognized that scientific investigation supplements rather than displaces the need for a rapid plant repair capability in the short term. The longer-term benefit is that faults arising from generic deficiencies will be greatly reduced or eliminated.

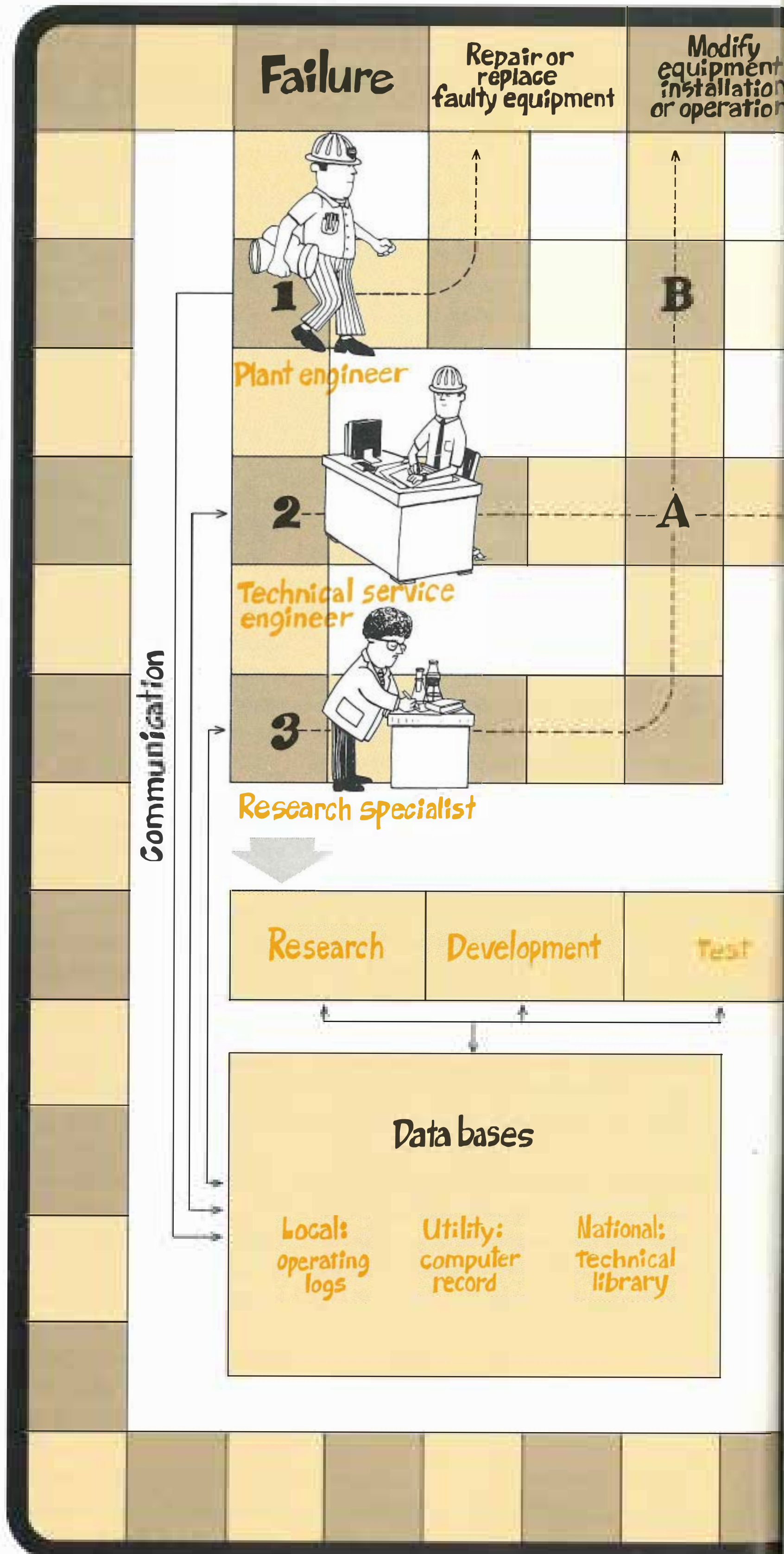
The specialist's diagnosis

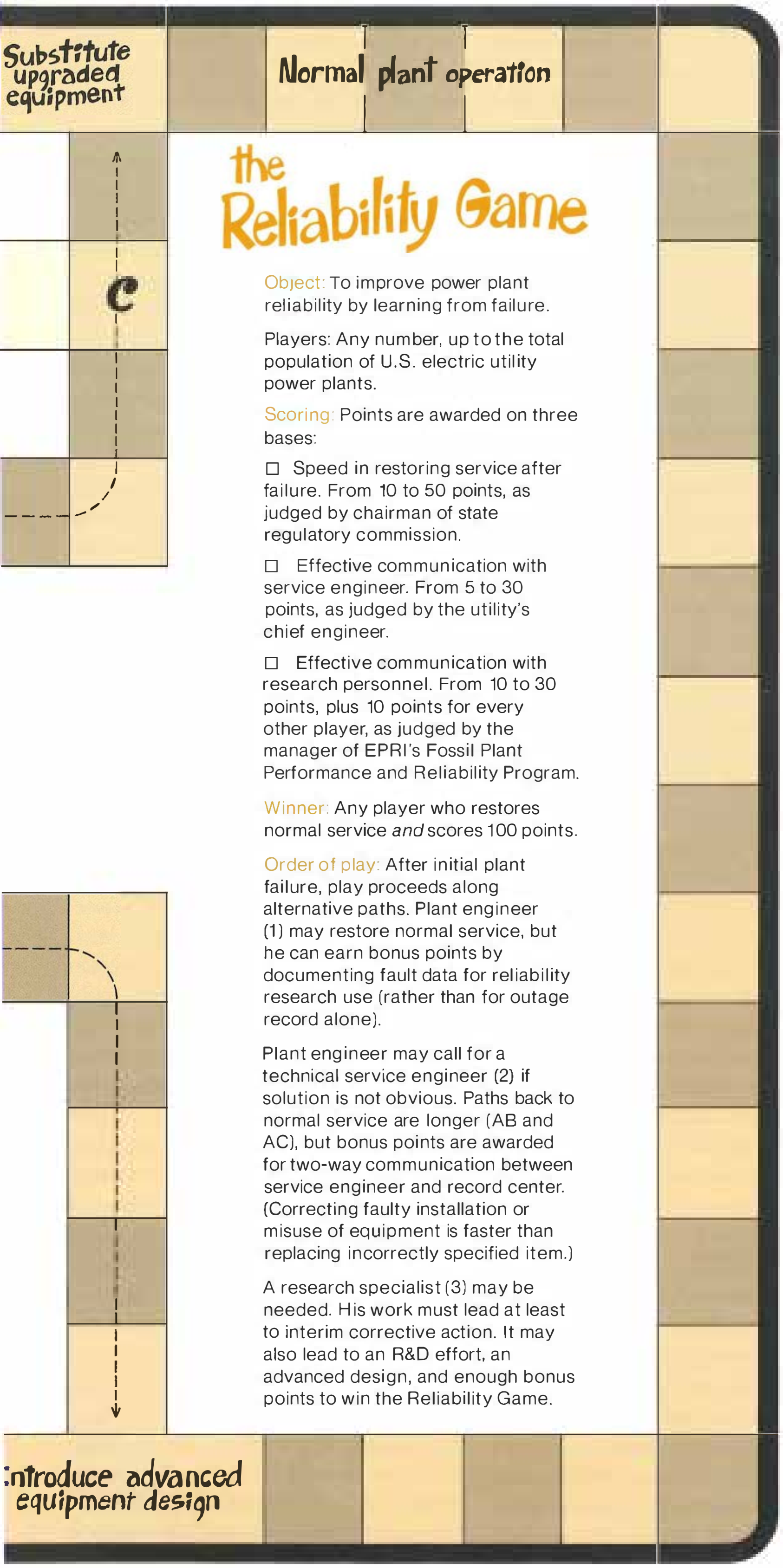
The reporting of a problem and the identification of the likely causal mechanisms must precede an effective detailed investigation. A key requirement is that the first report be made by an individual with a range of both engineering and scientific experience. He will not only know what questions to ask to form a preliminary diagnosis but will be aware of its limitations.

This person's role is somewhat analogous to that of the family doctor. In many cases he will recognize the symptoms, with a very high probability of being correct. Thus, a fault that is entirely new to the plant engineer is likely to be known to the "plant doctor," drawing upon other experience. In the event that a specialized opinion is needed, he will know what kind of specialist to call. Finally, a good "bedside manner" ensures the confidence and cooperation of the operating engineers with whom he deals. A person with a background in physics, chemistry, or metallurgy, and a bent toward engineering, often can perform this task well.

Record keeping

It is important that incidents concerning abnormal plant behavior be systematically recorded. Most utilities maintain





the Reliability Game

Object: To improve power plant reliability by learning from failure.

Players: Any number, up to the total population of U.S. electric utility power plants.

Scoring: Points are awarded on three bases:

☐ Speed in restoring service after failure. From 10 to 50 points, as judged by chairman of state regulatory commission.

☐ Effective communication with service engineer. From 5 to 30 points, as judged by the utility's chief engineer.

☐ Effective communication with research personnel. From 10 to 30 points, plus 10 points for every other player, as judged by the manager of EPRI's Fossil Plant Performance and Reliability Program.

Winner: Any player who restores normal service *and* scores 100 points.

Order of play: After initial plant failure, play proceeds along alternative paths. Plant engineer (1) may restore normal service, but he can earn bonus points by documenting fault data for reliability research use (rather than for outage record alone).

Plant engineer may call for a technical service engineer (2) if solution is not obvious. Paths back to normal service are longer (AB and AC), but bonus points are awarded for two-way communication between service engineer and record center. (Correcting faulty installation or misuse of equipment is faster than replacing incorrectly specified item.)

A research specialist (3) may be needed. His work must lead at least to interim corrective action. It may also lead to an R&D effort, an advanced design, and enough bonus points to win the Reliability Game.

records that permit the identification of problem areas and provide a first stage for setting broad research priorities, but these seldom furnish a deep insight into failure mechanisms.

Research aimed at economic problem solving must concentrate on generic faults; there is no interest in random events. The sorting and rejection of events therefore require some understanding of the causes of those events and inevitably involve the talents of trained people. Clearly, research needs differ from management needs in the degree of detail involved. In the first instance, all events affecting plant performance should be logged, but only a few will show up as systematic. This first stage is a station responsibility.

On a national basis, the Edison Electric Institute assembles statistics on investor-owned plant outages which, though a useful presentation of major failure classes, present too superficial a picture to be more than a starting point in the present context. Nuclear plants receive more detailed attention than fossil-fired plants; this reflects the industry's greater concern with a relatively new and sophisticated technology and the more stringent requirements of the Nuclear Regulatory Commission.

The involvement of research personnel in reporting leads to a second, entirely different level of information gathering and analysis. Initial reports are backed by laboratory examinations, hypotheses for failure mechanisms, and references to similar incidents, all of which are used to understand root causes and to initiate research programs where necessary.

Communicating research results

Publication of such data in a compact form of immediate practical value to the nonspecialist is impossible. Once again, therefore, a difficulty arises in communication and interpretation. Although computer files and data banks assist in the retrieval of information, there is a need for contact between the specialized scientists who have knowledge in particular areas and the engineers who need the benefit of that knowledge.

Direct contact facilitates the proper use of data, ensures that their limitations are recognized, and leads to feedback in both directions. Once a problem is properly understood, it should be possible to prescribe checks and treatments that do not require direct involvement of the specialist. This scientist therefore has a responsibility to publish data that will permit the operating engineer to solve such problems independently. Returning to the family doctor analogy, most common ailments should yield to home treatment and that treatment should become generally known.

Failures that are not well understood, or that do not respond to standard treatment, call for a link between the engineer and the library of partly digested scientific data. The obvious link is the same route used for incident reporting. Among other things, this ensures the availability of the most up-to-date information, in particular that which is still in the reporting process.

Ideally, then, there is a sequential need for complete records, communication of the problem to a "service scientist," specialized diagnosis, prescription of a studied solution, and practical application. Not all these steps are always involved, and a flexible, human approach is required.

A working approach

Recent experience of Britain's Central Electricity Generating Board is a good example of how a system that closely matches the needs has evolved. CEGB, with a total capacity approaching 60,000 MW, is responsible for virtually all power generation in England and Wales. Its service area is divided into five regions, each having its own administrative organization with immediate responsibility for plant operation. The national headquarters in London is responsible for overall finance, new plant specification and ordering, planning, and research. It also maintains substantial library and information services.

There are three major CEGB research laboratories in southern England, employing some 2000 people and forming parts of the headquarters organization. The major part of the laboratory facilities has been built up in the past 15 years. During this period, emphasis has shifted from the examination of novel power-generating systems to support for currently operating and planned units.

At the same time that the headquarters laboratories were built up, regional laboratories were organized, one attached to each of the five operating regions but with scientific coordination from headquarters. Their unique situation put them in an excellent position to develop the kind of technical liaison described earlier. Over the past decade these regional scientific services departments have increased substantially in capability, and they now collectively employ some 1500 people.

Each regional laboratory is well equipped to carry out physical, chemical, and metallurgical examinations, to set up specialized instrumentation, and to organize both plant- and bench-scale experiments. The research staff forms an essential part of a closely knit regional organization, and its members are regularly in touch with plant engineers. Most important, because of the small size of each geographic region, the research staff members are able to reach the site of any plant failure in a few hours and assist in on-the-spot diagnosis. Such rapid reaction is seldom necessary (and would be unduly distractive if called for too frequently), but the point is that communication at almost any level is easy and effective when required.

A range of activities

The involvement of scientific services staff ensures the exchange of experience between plants. In most cases this, together with the specialized advice that can be offered and the results of simple laboratory checks, is enough to solve the problem. If not, the appropriate headquarters laboratory can be consulted, and if a generic problem is identified, a national research program is established.

Troubleshooting is becoming a minor part of the regional scientific services activities as more problems become understood and are either eliminated or easily treated. Much of the work is now devoted to main plant testing aimed at providing data that will lead to trouble-free plant operation. Thus, all "first of a kind" boilers are equipped with an array of about 1000 measuring points to determine metal temperatures, heat fluxes, flow rates, and other data during the first year or so of operation. These are logged against operating conditions and used to check design parameters and to optimize operation so that conditions conducive to failures are avoided. Turbines have been similarly instrumented to measure stress levels and clearances during transient and steady operation, thus ensuring safe, rapid loading during load following. Telemetric devices have been developed to permit measurements on rotating parts.

Several CEGB headquarters research programs have yielded important improvements in plant reliability, such as those on welding (particularly of dissimilar materials) and on water chemistry associated with boiler tube protection and the related corrosion processes.

From time to time the cost-effectiveness of CEGB reliability research has been assessed. Although the results of such checks have been favorable, the only cases that can be positively quantified are those connected with corrective treatment. The most effective research is preventive; yet the more effective it is, the less opportunity there is for gauging its value, since the base case (no research) cannot be assessed with certainty. A research expenditure of about 1% of revenue to reduce failure risk of existing plant and to improve the performance of future plant has been considered realistic.

The U.S. scene

The British approach to power plant reliability research is not directly relevant to the U.S. utility community for a variety of reasons. There are major differences in industrial structure, and there is not the same need for utility-owned research facilities, since the principal equipment vendors are adequately equipped. There is, however, the same requirement for gathering detailed information on plant behavior and for analyzing it to decide where generic faults of design or operation exist (or where relevant basic data are lacking).

As in England, the first problem in reliability research is that of recognizing behavior patterns. Yet, the wide U.S. variation in fuel type and quality, water supply, generating unit size, loading, and utility size and resources aggravates this problem. The sheer size of the country eliminates the possibility of any sort of direct scientific service except in major industrial centers. EPRI must strive to serve not only these centers but all of its members. A way must somehow be found for collecting, sifting, and collating data on plant problems so that EPRI can formulate and place relevant research contracts.

Of course, outright failures are almost universally reported now. But problems that do not cause failure are not regularly reported and may be dealt with in various ways—from sledgehammers to prayer. Research personnel want to know about both, because a problem on one plant may become a generic failure on the next.

Above the power plant level there is no consistent technical coordinating structure in the U.S. Management is usually at the level of a corporation controlling several power stations. Small corporations may join together in holding companies, which may or may not have central services for engineering or research. While most investor-owned utilities make plant performance reports to EEI, cooperatives and municipal utilities have their own national representative bodies. Two consequences of this situation are that there is no common basis for reporting and no single reporting network.

New EPRI program directions

EPRI has for some time had a program of nuclear plant reliability research, motivated to some extent by the association of reliability with safety (as well as by the not altogether justified association of unreliability with risk). In the less regulated field of fossil-fired plants, the pressures for reliability are solely practical ones, and EPRI's effort has been more limited. Recently, however, it was decided to give program status—and a separate budget—to this effort.

Much of the data gathered during early discussions of the new program are qualitative rather than quantitative, and for this reason a large proportion of initial program funding will be used to sponsor technical surveys and assessments as bases for specific research projects. This approach can be considerably reinforced as electric utilities strengthen their own technical service capabilities to form links between power plants, on the one hand, and EPRI's centrally sponsored research, on the other. Through provision of fundamental and generic information, many essential feedback loops will thus be completed.

Already there are a number of areas where the need for generic data is clear and where a joint utility-vendor program is indicated. Work is being considered or is actually in hand, for instance, on the definition of impurities in coal that lead to boiler fouling and slag formation, on the testing of materials and the search for better ones, on the causes of pump failure, on phenomena that precipitate wetness in steam, and on corrosion-accelerated fatigue in turbine blades.

A major function of research groups is to ensure that available data are published and sources identified. EPRI has established research contacts with organizations of electric generating interests in Britain, France, Japan, and Canada. Inevitably, many problems leading to reduced reliability have been experienced—and perhaps solved—in one or another organization, and interchange of information should be helpful. The fact that both the French and the British electric generating industries are nationalized and have integral research facilities means that they should have exceptionally well documented statistics. Certainly, much of the CEGB data will be of interest in the U.S. and could be made available by contracting for the preparation of appropriate reports.

Precautions and guidelines

Unfortunately, both manufacturers and users of equipment are cautious about discussing performance deficiencies, especially when these may affect their markets or prestige. For this reason, the free exchange of all data is unlikely; but in those cases where a general failure mechanism has been identified, it should be possible to discuss it usefully.

Within the U.S. there should be fewer inhibitions than when foreign organizations are involved, and communication problems are likely to be practical rather than political. A number of utilities have developed their own problem-reporting systems, and there could be considerable advantage in finding what these systems have in common and to what extent it would be practicable or desirable to develop a single consistent data base from such established or evolving records. If undertaken, such development should pay as much attention to data analyses and retrieval as to recording. There is no doubt that modern computer techniques and equipment make this a far more practical proposition than ever before, but there is a potentially large institutional problem. Records should be at least comparable from one system to another.

Clearly, EPRI can perform a useful role in the collection, analysis, and publication of technical data relating to plant reliability, as well as in the initiation of R&D to solve some of the generic problems. In this role it will be important that EPRI supplement rather than duplicate efforts of existing bodies.

Looking ahead, EPRI may help the utility industry set uniform standards of testing, performance evaluation, and quality control that will do much to improve reliability of future plants and to eliminate cost discrimination against better quality equipment.

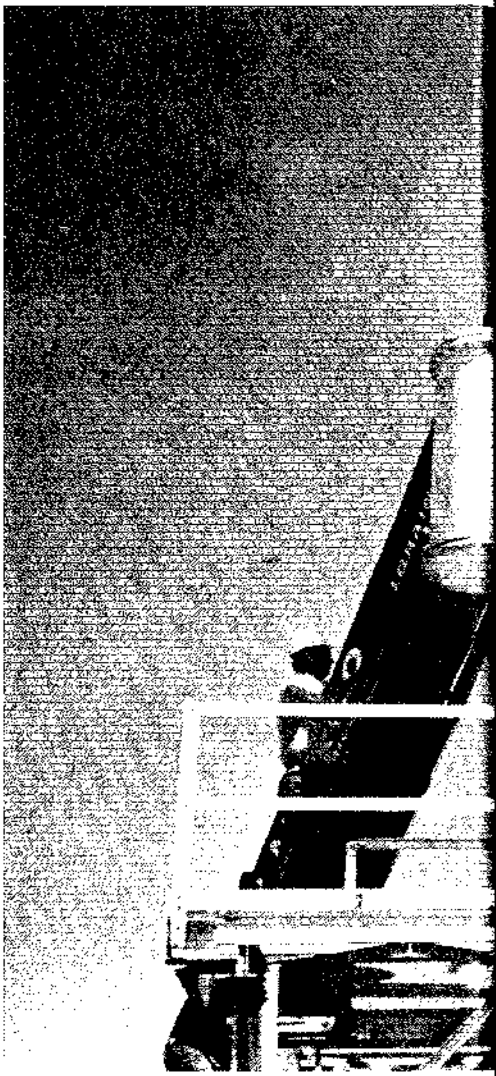
Improving Gas Dielectric Performance for Substation Design

by Walter A. Johnson

Dielectrically 2½ times stronger than air, SF_6 insulation competes today because it cuts the need for suburban land and structure. But the gas and equipment are costly. To gain a consistent economic edge, present design limitations must be overcome.

□ An EPRI technical article

Walter Johnson, principal engineer for substations with Potomac Electric Power Co., is on loan to EPRI as a staff member in the AC and DC Substations Program of the Transmission and Distribution Division.

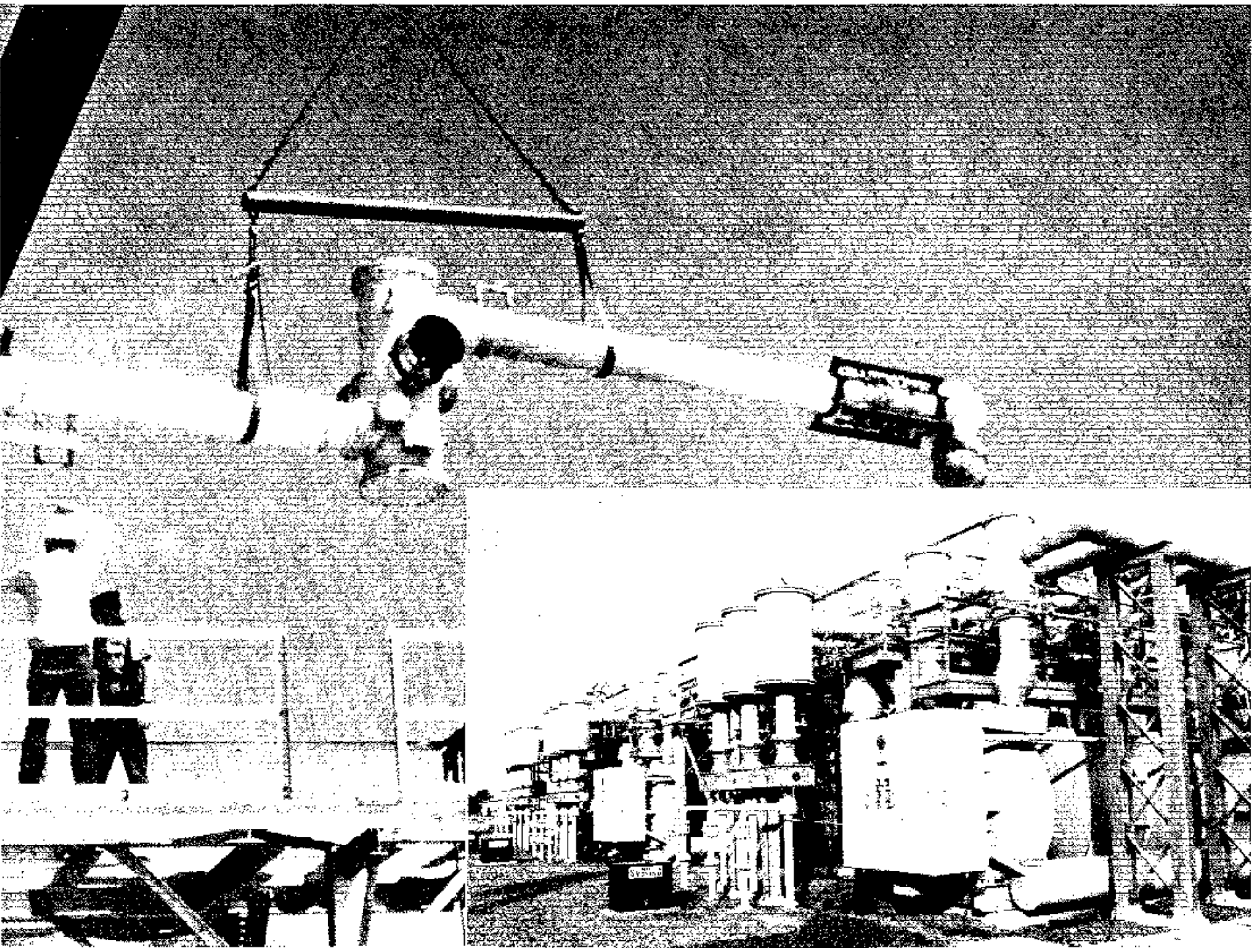


Gas-insulated 230-kV bus section drops into position at an Arizona Public Service bulk power and distribution substation in Phoenix. Pothead canister at left is 33 in by 4 ft; the air-insulated equivalent would be 36 in by 10–11 ft. Photo courtesy I-T-E Imperial Corp.

Three 3-phase underground circuits—with room for a fourth—feed a rank of 9 gas-insulated potheads along one 70-ft side of the substation. Pothead canisters are 3 ft apart, as compared with the 15-ft clearance that would be needed for air-insulated 230-kV buswork. Photo courtesy I-T-E Imperial Corp.

By reducing land requirements as much as 90% and field construction costs as much as 30%, gas-insulated substations (GIS) are solving severe problems. Yet today's designs are forced to use sulfur hexafluoride (SF_6) gas at pressures below 50 psig and at electric stresses below 325 kV/in crest voltage. Within these limits, the systems perform well, but their material cost is high because of this conservative design.

As GIS designs are extended to higher voltages and as manufacturing costs rise, production-scale economics alone will not ensure a competitive edge in installed cost. A key design need is to improve the performance of the gas dielectric.



The prospect of better GIS design is tantalizing to electric utility substation engineers, who have seen installed costs of air-insulated equipment more than double over the last seven years. Foremost among the causes is the annual cost increase of between 10 and 15% for all types of field construction and labor. Second is the near doubling of substation equipment costs since 1970. And third is a steady increase in the sophistication of relaying, control, and communication systems.

In response to this escalation, use of GIS equipment is already cutting construction costs because of the dramatic reduction in site preparation and because of the large, factory-tested and -assembled sections in which the equipment can be shipped. It also eases the relaying and control problem by drastically reducing the length of control cables and eliminating shielding requirements. However, at all but the highest voltages (say, 345 kV and up), GIS hardware now costs up to twice as much as air-insulated equivalents, so the overall saving that can be achieved is reduced.

Another important reason for improved designs is to comply with land use planning restrictions. Many local zoning boards already question air-insulated facilities on the basis of land use and esthetic acceptability. EHV and UHV facilities may meet outright resistance. The small size and low profile of GIS equipment provide an excellent alternative if the installed cost can be equal to or lower than that of air-insulated designs.

Application history

It has been 40 years since a researcher is reported to have picked SF_6 out of a chemical handbook. He believed that its symmetrical arrangement and atomic structure best met the chemical stability and electron attachment requirements he had postulated for a superior electrical insulating gas. Indeed, although several gases have since been found to have better dielectric characteristics alone, none has yet matched SF_6 in overall balance of dielectric performance, moderate cost, low reactivity, low toxicity, low boiling point, and good thermal transfer characteristics.

The dielectric breakdown characteristic of SF_6 is compared with that of nitrogen in Figure 1. Nitrogen is similar to air in this respect, and the high-voltage metal enclosures needed for nitrogen would be impracticably large.

Early applications of SF_6 were in high-voltage X-ray power supplies. Its use as a dielectric in electric power equipment grew quite slowly, largely because construction costs and land use problems were not critical.

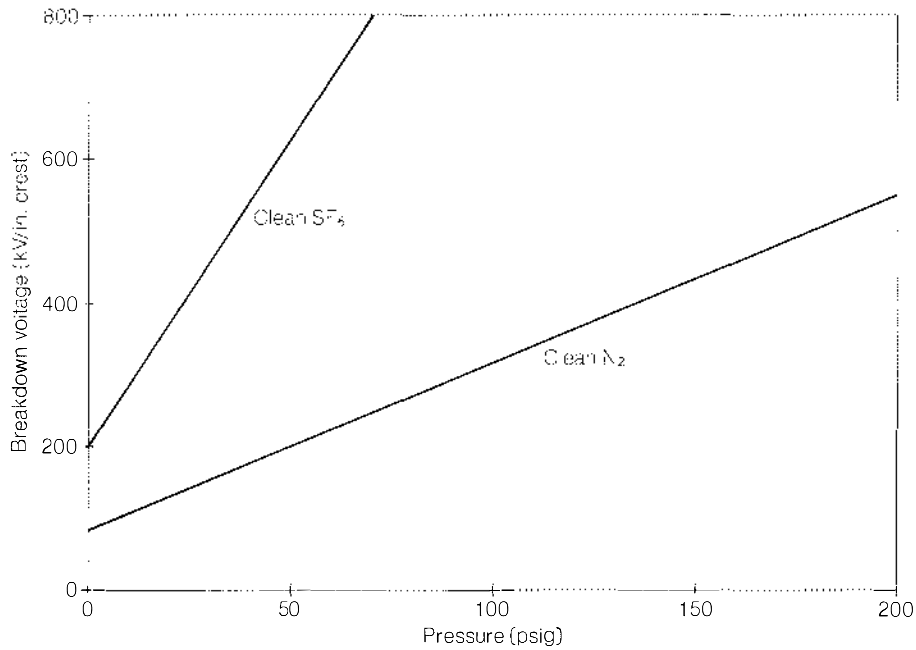
By the mid-1940s, however, work on electric arc interruption revealed that SF_6 had superior characteristics for arc quenching. This discovery led SF_6 to become one of four major arc interruption media (along with air, oil, and vacuum) used in power circuit breakers. Such renewed interest, together with a steady increase in system voltages, resulted by 1960 in the common use of SF_6 as an internal dielectric in current and potential transformers for air-insulated applications. Other uses included high-frequency waveguides, scientific apparatus, and atomic particle accelerators.

Japan and several European countries (France, Germany, Netherlands) were the first to justify fully gas-insulated substations. During the late 1960s, a number of GIS installations up to 145 kV were placed in service. The technology became commercially available in the United States in 1970, and a year later the first gas-insulated substations and short transmission circuits were energized. Since then, 24 U.S. electric utilities have purchased one or more systems, rated from 69 to 500 kV. Prototype and development work at 765 and 1200 kV is underway.

Gas dielectric limitations

If the theoretical dielectric performance of SF_6 could be achieved in actual systems, there would be little need for further research. Several factors, however,

Figure 1 Clean N_2 (similar to air) in a uniform field provides a reference for comparing the dielectric superiority of SF_6 at various pressures. Even at atmospheric level, SF_6 has a 2:1 edge, which increases to 3:1 at 50 psig. Although the SF_6 breakdown value is 650 kV/in at that pressure, in today's design practice it is held to a maximum of 325 kV/in to allow for the degrading effect of contaminants in a gas enclosure.



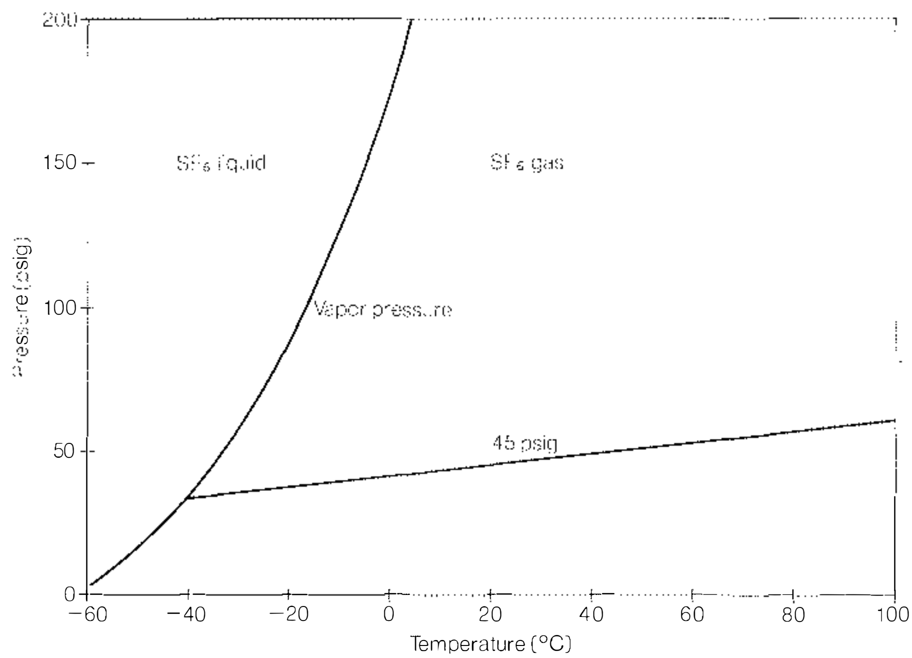
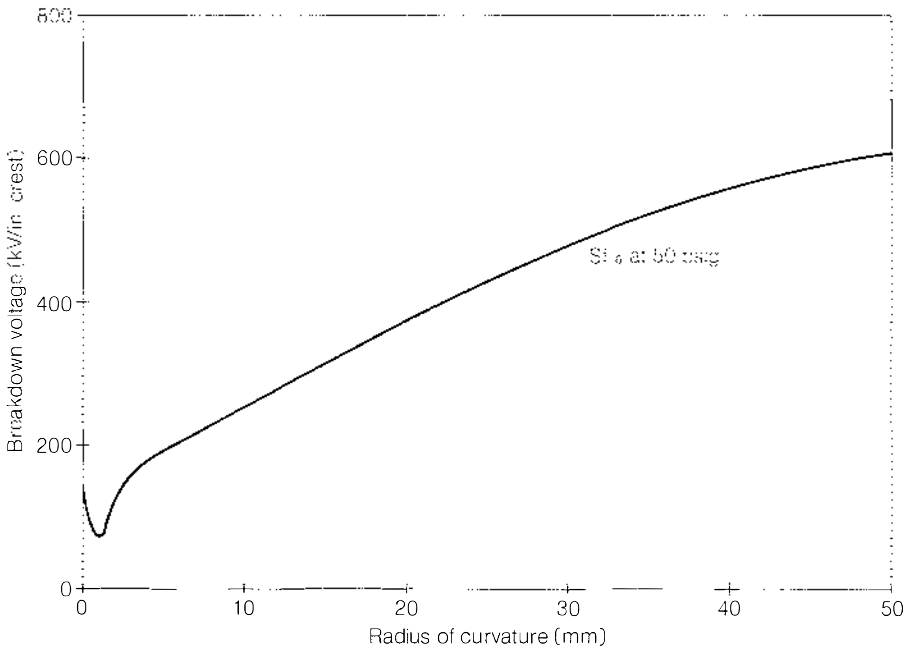


Figure 2 Vapor pressure curve of SF_6 denotes the dew point temperatures at various pressures. For a specific gas volume (in this case corresponding to 45 psig at 20°C), the dew point is −40°C. Use of higher pressure for better dielectric performance must be weighed against a higher dew point and the possible need for heaters to avoid gas condensation in cold weather.

Figure 3 SF_6 breakdown degrades in the nonuniform field created by a sharply curved component or structure. Good design practice therefore emphasizes smooth surfaces (curvatures greater than 20 mm) inside gas-insulated enclosures—but at some penalty in equipment size.



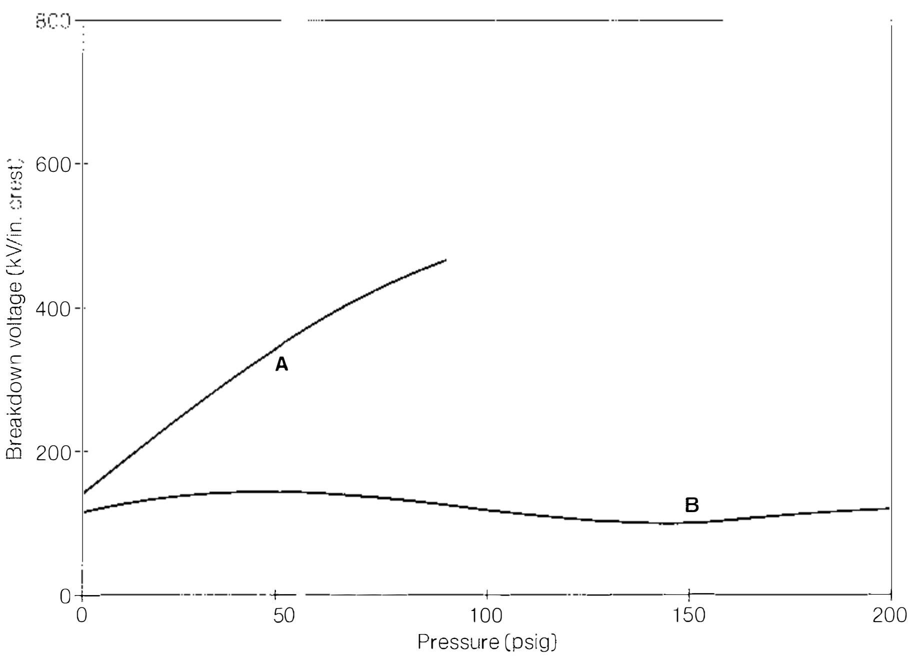


Figure 4 Dielectric quality of clean SF_6 gas in a coaxial field (Curve **A**) is sharply curtailed by free conducting particles, such as ½-in wire fragments (Curve **B**). Empirical data show the best performance to be at pressures between 25 and 50 psig, but it is evident that purging or trapping contaminants would significantly raise the SF_6 breakdown level.

reduce its present capability to the relatively low value cited earlier: 325 kV/in.

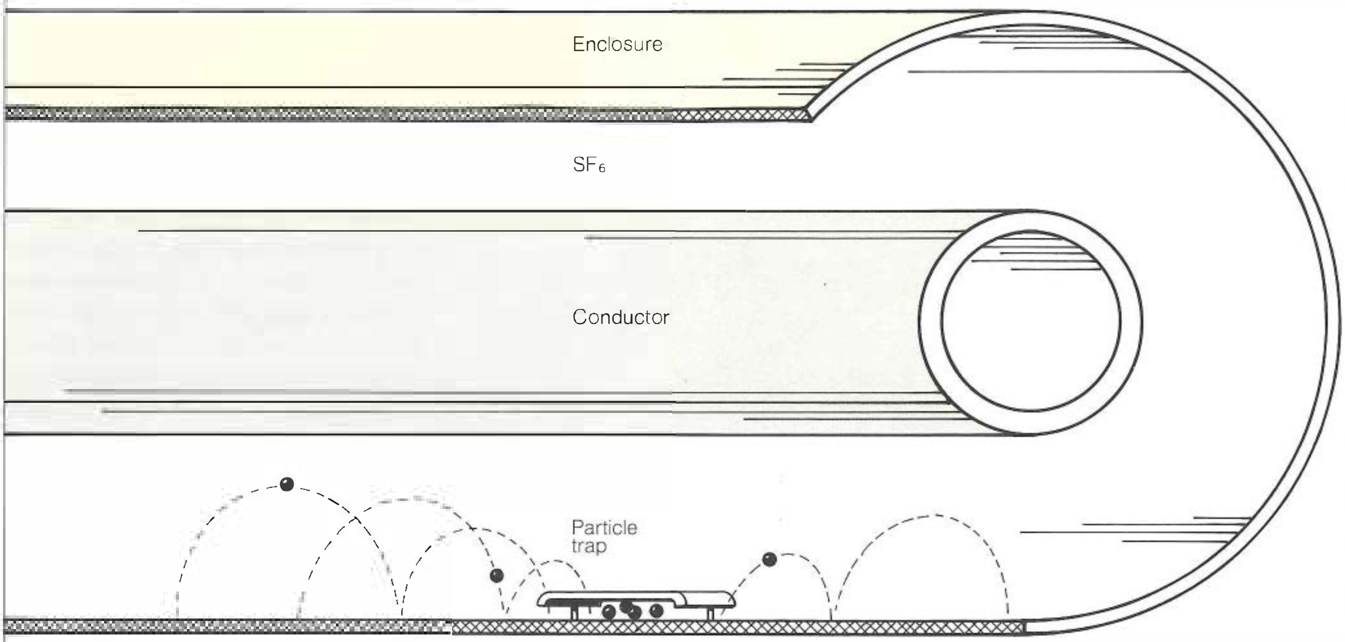
The first limitation is common to all gases used in dielectric applications: the gas must be maintained at a temperature from which, at the pressure of utilization, it cannot fall to the dew point. Below this critical point, condensation of the gas or of any entrapped moisture destroys its dielectric withstand capabilities. Figure 2 indicates that for outdoor installations in most parts of the U.S., heaters would be required for operating pressures above 60 psig. This limitation can be overcome (reliable heaters have been used on power circuit breakers for years to warm high-pressure compartments that operate with SF_6 at 250 psig), but not without a cost impact.

The second limiting factor is somewhat more difficult to overcome. Experience and experiments show that the dielectric performance of SF_6 is severely reduced in nonuniform fields (Figure 3). Large, smooth surfaces do not degrade dielectric performance, but relatively small or sharp protuberances result in low dielectric withstands. The solution, so far, has been to use carefully rounded and shielded parts, as well as large clearances between them and the enclosure. These measures increase the mass and volume of the equipment, the amount of gas required, and the cost of the resulting system.

The third factor limiting the performance of SF_6 is the presence of surface roughness and free conducting particles. Regardless of manufacturing and installation precautions, it is impossible to preclude these entirely, and the theoretical basis of their effect (Figure 4) is not yet fully understood. As a result, the peak dielectric withstand for today's practical systems occurs below 50 psig. Even at this pressure, the withstand is less than half of what would be achievable if the SF_6 were in an uncontaminated field. These factors force present designs to stay at low stress levels.

All gases (even air at atmospheric pressure) exhibit these dielectric limitations to some degree, and for the same reasons:

Figure 5 Typical particle trap in a gas-insulated enclosure is a sheltered region of low electrical stress. During a conditioning period before the system is put into service, free conducting particles bounce randomly, impelled by a selected ac voltage, until they migrate into the trap and are thus permanently immobilized. Monitoring of partial discharges determines when enough particles are trapped to ensure high dielectric performance of the SF_6 under service voltage stress.



dew point, nonuniform fields, and particulate contamination. The difference is in the nonlinearity exhibited by SF_6.

Research directions

Efforts to overcome or circumvent SF_6 limitations take three forms: basic research into the breakdown phenomenon; development of "particle traps" (protected low electric field areas within the system) and methods to condition the system so that free particles will migrate to the traps; and investigation of new gases, gas mixtures, or gas dopants (small amounts of some gas added to the SF_6) that will provide superior performance.

Several projects have been conducted to study the breakdown phenomenon, including one in progress under the joint sponsorship of EPRI and ERDA. A complete model of the breakdown mechanism has not yet been developed, but a large body of practical data has been obtained experimentally. For example, the reduction in SF_6 breakdown voltage has been correlated with pressure and with the size and shape of protuberances and free conducting particles. Also, SF_6 is being compared with other pressurized gases so as to establish a relationship between molecular structure and amount of breakdown degradation. Other aspects of this work involve investigating the fact that dc-energized systems are affected more strongly than ac systems. The EPRI-sponsored work, together with what is being done in other investigations, promises to improve our ability to understand and model the dielectric performance of SF_6. This is essential if the other research directions are to be more than empirical attempts at a solution.

Particle traps have been developed by several manufacturers, and some presently available GIS equipment includes first-generation designs. Figure 5 describes the basic operation of a typical particle trap employed to purge gas-insulated structures of free conducting particles that inevitably remain after manufacture and assembly. The voltage level required to lift a particle from the bottom surface of the enclosure is a function of the mass of the particle, the charge it acquires, and the electric field strength. Under ac conditions there is a wide range between this voltage and the voltage required to make the particle move to the conductor itself. When the voltage is held within this range, however, particles bounce randomly, and if a region of low (or zero) electrical stress is provided, they will ultimately bounce into that region and be trapped.

Another research pursuit is an evalua-

WHO WANTS GIS EQUIPMENT AND WHY

EPRI surveyed a cross section of U.S. electric utilities for their perceptions of GIS criteria. Among the 73 respondents were 16 of the 24 present users of gas-insulated substation or transmission equipment.

Within the total response, 60% have considered GIS equipment, either solely at the planning stage or by obtaining bids as well. The other 40% cite, as reasons for not considering GIS equipment, an absence of land use pressure or a belief that the equipment would be too expensive. Among the 60%, four issues were judged to be of significant concern in GIS justification: cost, reliability, repair time, and construction and maintenance difficulty. Cost was seen as less of a concern by utilities that have received firm bids on equipment.

When asked about research activity beyond what is already underway, respondents indicated the following priorities:

- A GIS design reference book
- Lower-cost designs
- Designs for devices not now available (e.g., carrier line traps)
- Repair and maintenance techniques

Interestingly, this list (now being considered in EPRI program planning) does not include investigation of other gases or mixtures that may have better properties than SF_6. As pointed out in the accompanying article, the currently applied stress limit in SF_6 controls the size (and thus the cost) of today's designs. Therefore, this research is very significant even though its basis is not well known in the industry.

tion of gases, gas mixtures, and dopants that, in place of or in combination with SF_6, exhibit superior dielectric performance. This is not an easy undertaking; 40 years of off-and-on effort have been unsuccessful. On the other hand, a fully systematic study has never been undertaken, and our capability to synthesize candidate compounds has advanced considerably over the years. While this research necessarily includes checking costs, toxicities, reactivities, etc., its main goal is to achieve lowered dew points and improved performance under conditions of nonuniform fields and free conducting particles.

Prospects of success

Results to date, from both the basic research projects and the development of particle traps, are very encouraging. The basic research has developed analytic models that accurately describe SF_6 system performance with free conducting particles present. SF_6 characteristics are now being evaluated relative to other gases, and spacer insulators are being studied for their influence on the breakdown phenomenon. The outcome should permit new designs to be analyzed and optimized by computer simulation rather than only by trial-and-error methods.

Highly effective particle traps are also being developed very rapidly, together with electrical and mechanical techniques to scour the systems. These should permit increases of up to 50% in the design dielectric stress level of a constant amount of SF_6. When they are proved in use, it will immediately be possible to improve GIS equipment performance in one of three ways. First, the operating pressure of the bus could be reduced, with no decrease in the prior basic insulation level. This would markedly reduce the amount of gas required to charge a system—a significant improvement over current designs in which SF_6 alone represents up to 5% of GIS and 10% of transmission equipment costs. The second possibility would be to achieve higher basic insulation levels, where required, at current design pressures. The third alternative would be smaller systems operating at present pressures. This is the major payoff—reduced equipment mass and gas requirements.

Research into gases, gas mixtures, and dopants has been underway for some time but will require two years to complete. A new EPRI project, designed to be comprehensive, will investigate arc interruption characteristics in addition to dielectric performance. The possibility that gas mixtures may permit a significant reduction in cost is very promising, since earlier work shows that a 50-50 mix of SF_6 and N_2 has 90% of the dielectric strength of pure SF_6. Discovery of appropriate dopants to improve SF_6 performance in nonuniform fields would enable GIS equipment to be built with many fewer shields and grading rings, a distinct manufacturing economy.

As in the case of particle traps, a breakthrough would permit using less gas, enhancing performance with the present amount of gas, or making the equipment physically smaller. The choice would be based on the most cost-effective balance of material and gas quantities.

Taken in total, the improvements from current research may result in doubling the design dielectric stress level of all gas-insulated equipment. It seems likely that major advantage of this improvement will be taken in simplified, smaller (lower mass) designs. The effect on cost would be immediate for transmission equipment and when coupled with improved manufacturing techniques, will also make GIS equipment more attractive. If all the research efforts are successful and their results implemented, the equipment in a typical 500-kV GIS installation might be cut 40% in size, 30% in weight, and 60% in gas requirements.

R&D Status Report
TRANSMISSION AND DISTRIBUTION DIVISION

John J. Dougherty, Director

DISTRIBUTION

During the past few months several distribution projects have been completed, a few have been extended, six new projects have been funded, and the funding for one has been increased. Final reports for the projects that have been completed will be issued shortly.

One project with ECP, Inc. (RP482), has demonstrated that it is possible to manufacture all sizes of power poles from foamed glass with fly ash filler. The tensile strength of large samples is 5000–6000 psi, which is comparable to that of three types of wood now used for poles. The impact resistance is equal to or greater than that of concrete.

Approximately five million new wood poles are purchased annually by the industry at a cost of $500 million. Savings of 30–70% (depending on pole length and strength requirements) over the cost of new wood poles is anticipated. Assuming only a 5% initial usage (250,000 poles), a $12.5 million average annual savings could be realized.

The objective of a newly funded research project is to systematically develop, test, and deliver power poles manufactured of foamed glass and fly ash. Two major efforts are involved: (1) to produce, test, and evaluate the operational properties of a 40-ft power pole, and (2) to develop a continuous process for pole production by designing and specifying process equipment, establishing and qualifying a pilot production facility, selecting the optimal combination of foamed glass components, and testing a series of full-scale power poles.

A project with Michigan Technological University (RP796) complements the foamed-glass pole research. Its objective is to develop the technology of making composite poles from wood particles that are bonded together with synthetic resins. This will provide another source of material for poles that is not dependent on solid roundwood material. The raw material will come from abundant wood residue or tree species that have little or no commercial value. Preliminary studies indicate the particle pole will be competitive in cost for poles up to 50 ft and less expensive for longer poles.

Another new research project is a series of field demonstrations of communication systems for distribution automation (RP850). Six utilities will serve as hosts for pilot tests of six communication concepts. Three of the host utilities will work under EPRI contract and three under ERDA contract. Approximately $7 million has been allocated by EPRI and ERDA for this three-year project.

The pilot tests are intended to demonstrate the feasibility of automatic meter reading. Each system will also attempt sectionalizing equipment control, status monitoring, fault location and isolation, simulated load management, and time-of-day metering. Following the successful demonstration of the communication systems, research projects will be initiated in the management of the available data and the development of new operating techniques. It is also expected that necessary equipment improvements will be identified during this test program.

SUBSTATIONS

In two new projects, the use of SF_6 in power equipment is being investigated. Westinghouse will evaluate the use of SF_6 instead of nitrogen in the gas space above the oil in power transformers (RP808). It is hoped that replacement of nitrogen with SF_6 and other gases will improve the electric insulating and/or cooling performance of the system. The study will be in sufficient detail to evaluate solubility, electrical properties, gas evolution and absorption, convection effects, compatibility, stability, corona performance, and metal reaction. If no adverse effects are discovered, it may be possible to eliminate oil condenser bushings on transformers that interface with gas-insulated substation equipment. This will produce savings in cost, space, complexity, and maintenance.

A second project with Westinghouse and E. I. DuPont de Nemours (RP847) will investigate the potential use of dielectric gases as alternatives to SF_6. There are gases for insulation and interruption that are known to have properties superior to those of SF_6. DuPont will procure and determine the physical and toxic properties of the test gases and prepare the manufacturing cost estimates of the gases finally selected. Westinghouse will investigate the insulation and interruption characteristics.

A major use of SF_6 is in circuit breakers. It is estimated that a less costly gas that is also superior in dielectric strength could result in annual savings of $6 million per year. Based on present costs, a less expensive overall circuit breaker using such a gas could result in annual savings of $12 million.

SYSTEM PROTECTION

The EPRI system protection effort is designed to provide both improved fault current control (interrupters) and fault current limitation as alternative options.

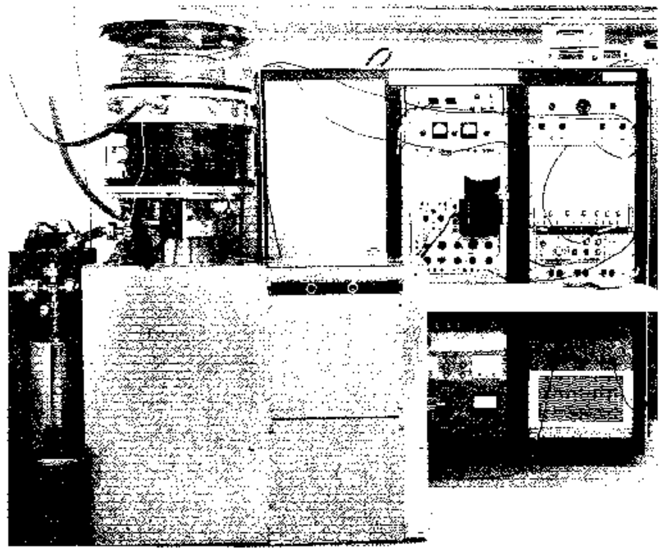
The interruption of fault currents has traditionally been handled by fuses, reclosers, and power circuit breakers. Fuses are low in cost but are limited in application due to single operation, low continuous-current-carrying capability, limited voltage, current interrupting ability, and coordination problems. Reclosers are limited at higher voltages and higher continuous currents.

Power circuit breakers can handle today's high continuous currents, voltages, and interrupting capabilities, but they are large, complex, and costly. System growth is constantly increasing the rating requirements for these devices, which further increases costs. Increased interrupting requirements also make it necessary for utilities to replace existing equipment while it is otherwise still useful. So in addition to providing increased interrupter ratings at a reasonable cost, we must also find ways to limit fault currents.

A project with General Electric Co. is investigating arc interruption in gas flows (RP246). The first phase of this two-year project will be completed this year. The use of new analytic techniques has resulted in a better understanding of arc behavior near zero current as it is influenced by pressure and gas flow. This, in turn, should lead to improved gas interrupter designs that will meet higher duty requirements with more simple, more reliable interrupting devices. A related project with the University of Pennsylvania will establish mathematical models of arcs and the dielectric recovery following zero current interruption (RP379).

Westinghouse Electric Corp. has a project to develop a single-pressure SF_6 interrupter rated at 120-kA at 145-kV in 1.5–2.0 cycles (RP478). The approach is to evaluate interrupter designs that use high-pressure SF_6 gas or liquid SF_6 to achieve the desired rating. The one that will best meet these requirements will then be selected, and Westinghouse will design, build, and test a prototype interrupter. The use of a single-pressure SF_6 system should provide power circuit breakers of greater reliability with lower costs and maintenance requirements than present two-pressure designs.

An ongoing distribution project on fuse development (RP428) should result in designs for 15-kV current-limiting



Vacuum test chamber, controls, and instrumentation for a magnetically controlled fault current limiter under development at the State University of New York at Buffalo.

fuses that will have higher continuous current capabilities in a single barrel. Current-carrying element configuration, fill gas atmosphere, and aggregate filler additives have been studied by the contractor, Allis-Chalmers. An element design has been tested that promises higher continuous current ratings without sacrificing interrupting ratings. This project should be completed by the end of 1976.

Not all development is directed toward higher voltage and current ratings. A project with I-T-E Imperial Corp. (RP661) has a two-fold purpose. One part of the effort is directed toward the development of an SF_6 interrupter for use in the 15–72.5-kV voltage class outdoor power circuit breakers and in metal-clad switchgear. The other part is the development of a hybrid breaker that combines the best features of vacuum and SF_6 interruption for 115- and 145-kV application. If successful, these efforts will eliminate the problems of oil flammability, will reduce size, and should lower maintenance costs.

To date, vacuum interrupters have been limited in current-interrupting and voltage-handling capabilities. This has resulted in their application primarily to lower voltage distribution class power circuit breakers. A project just getting underway with General Electric is a 40-month effort to develop an 80-kV, 80-kA vacuum interrupter bottle (RP754). The goal of this project is to produce a vacuum interrupter that will permit the design of a line of vacuum power circuit breakers. These should meet most of today's application requirements in the transmission voltage range.

The other side of fault current management is limitation. There are two aspects to this. One is to limit the value of the first loop of fault current. This value is mostly determined by the speed with which a limiting impedance is introduced into the circuit. The other aspect is to limit the steady state value of the fault current. This is determined by the value of the limiting impedance.

Equipment problems to be solved are high-speed detection, high-speed operation, commutation of fault current into a limiting impedance, and energy absorption and dissipation. System problems include device location, reliability, protective relaying, and economic evaluations.

Many of these problems were evaluated by I-T-E in RP281, for which a final report has been published. During the course of this project the investigators studied several concepts, including series-tuned circuits, superconducting active elements, and various methods that were proposed for commutating current into a parallel resistor. One system, which their studies showed was feasible for the near-term, is commutation of fault current into a parallel resistor with a current-limiting fuse. This combination was tested in model form, both in a high-power laboratory and on a utility system. RP281-2 with I-T-E involves the construction of a three-phase prototype, which will be installed and tested on Southern California Edison Company's 69-kV subtransmission system.

Other concepts for FCLs or their key components have not yet been advanced to the prototype stage. One such project is the development of a complete FCL using a variation of the simple series-tuned circuit. The novelty of this idea is in the circuitry, which can switch from a series-tuned to a parallel-tuned circuit during faults. Westinghouse is pursuing this development under RP654. Resistance can be added to the circuit so that many possible combinations of capacitive reactance, inductive reactance, and resistance can be optimized. This prototype is now past the computer modeling stage, and a laboratory model is being constructed.

The only other project EPRI has for development of a complete FCL concept is RP324 with Phoenix Electric Corp. in Boston. The contractor has produced and tested a model of a current limiter that consists of a single-turn conductor in an iron core with a variable air gap. Fault current causes the air gap to close, thus considerably increasing the inductance of the device. This project has been completed, and the final report will be available later this year. The contractor concluded that this has application potential and is prepared to supply the devices for trial installation.

Two other projects are underway to develop key components of a limiter system. The State University of New York at Buffalo is undertaking the development of a concentric vacuum device that was originally designed as a thruster for space vehicles (RP476). This device has impedance characteristics that can be controlled by application of a magnetic field. Preliminary model tests should be completed and feasibility established by December of this year.

The other component project is with Westinghouse (RP564) and also involves a vacuum device, but the mode of operation is different: this device is a switch in which arc instability is forced by application of a magnetic field. It can then be used as the continuous current-carrying means and as the commutation means. Both feasibility and design parameters are expected to be established by the end of the year.

SYSTEM PLANNING, SECURITY, AND CONTROL

An important new project in System Planning will attempt to determine the response of loads to system disturbances. Previous studies have shown that load response is a major factor that determines whether a power system will survive a major disturbance. This will be the first effort organized on an industrywide basis to study the behavior of a broad range of load types under large variations of voltage and frequency. The load response data will enable system planners to predict more accurately the stability limits of tielines. This, in turn, will enable planners to better define construction requirements and systems to operate closer to their full capabilities. Even a small improvement in the utilization of the bulk transmission facilities will result in large savings.

In RP849 a group of contractors will combine their efforts over a four-year period. The University of Texas at Arlington (UTA), working with several Texas utilities, will construct system load models by using a building block approach (i.e., defining the characteristics of individual electric appliances through laboratory test). After conferring with utilities, they will define the realistic composition of appliances at different times of the year and the many load types in a utility system that can be used to construct typical load models. General Electric, working with the New York Power Pool (NYPP), will validate the UTA models by staging system disturbances and measuring the load response, using sophisticated digital instruments. The Hydro-Quebec Institute of Research will provide General Electric and NYPP with the digital instruments for the test. A data processing specialist to assist General Electric in processing the test results will be selected later.

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

FISSION PRODUCT DECAY HEAT

The energy emitted by fission products represents about 7% of the power of a nuclear reactor during normal operation. In the event of a LOCA in the reactor, the neutron reaction would cease, and the major source of sensible heat would come from the beta and gamma rays emanating from the decay of the accumulated fission products. This energy, which is approximately evenly divided between beta and gamma radiations, has not been precisely determined, especially for the short times after shutdown ($\leq 10^3$ sec) that are vital in a LOCA analysis. The result is that extra margins of conservatism are included in the safety design of the reactor to ensure that the fuel pin cladding does not melt in the unlikely event of a LOCA. Under the current regulatory conditions, uncertainties in the decay heat translate into lower permissible operating power levels for reactors.

EPRI is currently supporting two experimental projects (RP230 and RP766) to provide reliable data on ^{235}U and ^{239}Pu with low variance. The expected accuracy of the experimental measurements is $\sim$3% (1σ), considerably less than the somewhat arbitrary 20% conservatism factor added in the requirement of the current ANS Standard 5.1. For less than 1000 sec, the standard relies mainly on theoretical arguments, extrapolations of other experimental data, and summation calculations from the isotopic decay chains of fission products.

The EPRI-supported work is being performed by the University of California, Berkeley (UCB), and IRT Corp., San Diego. The University of California project will irradiate its samples in a high-flux reactor and determine fission product afterheat, using a total energy calorimeter. IRT Corp. is using a ^{252}Cf-fission source to detect individual beta and gamma rays in a large-volume scintillation detector. Other experimental projects that are related to the work at EPRI are underway at Oak Ridge National Laboratory and Los Alamos Scientific Laboratory (LASL), and calculatory procedures based on the summation technique are being developed at Oregon State University, Hanford Engineering Development Laboratory, and LASL.

Data on ^{235}U fission product afterheat have already been obtained by IRT Corp., and the UCB results are expected by late summer of this year. Review meetings are periodically held with all interested parties, including other decay heat investigators, NSSS vendors, and NRC personnel, to compare data and to ensure maximum dissemination of the results. *Project Manager: F. J. Rahn*

EPRI WORKSHOP ON SYSTEM CONTAMINATION

Nuclear power plant radiation levels appear to be increasing in the plant work areas at an annual rate of 25–150 mR/hr, and average annual occupational radiation exposures per plant have nearly tripled since 1969. Although increases are to be expected, the NRC has requested operating plant personnel to maintain radiation exposures to "as low as reasonably achievable" (ALARA) values.

While the radiation exposures have been carefully controlled, achieving the ALARA criteria can significantly affect the time required to do even the simplest tasks and, consequently, have an impact on plant availability and reliability. Approximately 80% of the personnel exposure is received during plant shutdown for refueling and equipment maintenance. Such radiation exposures add complexities to nuclear power plant operations that reduce productivity and thus increase the cost of power generation in such plants. (The expense of radiation exposures may amount to tens of millions of dollars over the lifetime of a plant.) Costly efforts, such as the multimillion dollar Dresden-1 chemical decontamination, are in progress to reduce shutdown radiation levels.

A major emphasis in EPRI's nuclear research activities has been to improve plant reliability and availability. Part of this rather broad objective can be achieved by reducing plant radiation levels, using techniques that have only minor effects on plant availability. It is expected that contamination control techniques combined with appropriate decontamination methods will achieve this objective.

As an initial step toward obtaining industrywide input in the area of contamination control, a 2 1/2-day workshop on system contamination was sponsored by the Nuclear Power Division March 15–17, 1976, in Atlanta, Georgia. The purposes of the workshop were (1) to have highly qualified experts present state-of-the-art information on radioactive contaminant characterization and contaminant control techniques and (2) to obtain guidance on research programs that will result in lower plant radiation exposure levels. The workshop was attended by 54 specialists representing 19 utilities, 8 consulting firms, 4 NSSS vendors, 3 laboratories, 3 architect-engineering firms, and Atomic Energy of Canada, Ltd.

The first 1 1/2 days of the workshop were devoted to presentations by 19 speakers and a discussion by a four-member panel. Technical state-of-the-art presentations on both known and needed information were given in the areas of physical chemistry, preoperational practices, corrosion-product characterization and modeling, metal oxide processes, and radiation levels and occupational exposures in nuclear power plants. Presentations on contamination control covered the topics of chemistry techniques, operational methods, high-temperature filtration, ion exchange, design practices, and exposure management.

The last day of the workshop was reserved for task group meetings. The attendees were divided into seven 6–8-member groups to develop research program recommendations within selected technical areas, and 41 recommendations were presented by the task group leaders. These recommendations have been summarized in nine general areas, as follows:

Standardized Utility Data Base Standardize chemistry, corrosion-product, and radiation level measurement procedures for use in nuclear power plants. Associated with this, develop a data storage and retrieval system that can be used by all U.S. utility companies.

In-plant Data Collection Programs In addition to the utility data storage and retrieval system, develop complementary and comprehensive in-plant data collection programs in corrosion-product characterization and trending, performance of existing purification and filtration systems, and radiation exposures associated with specific maintenance and repair activities. (In all cases, employ standardized data collection techniques.) Develop a corrosion-product transport model from these data to use in evaluating methods to estimate and control plant radiation levels.

Optimum Chemistry Control Optimize primary system chemistry parameters to minimize material corrosion and failure. Evaluate chemical additives and/or operational techniques that can be used to control plant radiation levels, with a minimal effect on material performance. In addition, evaluate the relative effect of preoperational, startup, and shutdown practices on plant radiation levels.

Laboratory Studies After thoroughly reviewing existing data, conduct complementary laboratory studies in the basic areas of high-temperature corrosion-product solubilities, pH and temperature effects on particle charge, particle deposition, and particle release rates.

Alternative Material Selection Conduct a program to determine which materials are prime contributors to the radioactive corrosion-product inventory. Evaluate alternative materials or specifications that could be used in the primary system to reduce these contributions.

Design Review Audits Develop a system whereby the effects of plant design on radiation levels can be provided and retrieved by all utilities (the radwaste system was given as an important example). In addition, establish the importance for utility design review audits on radiation exposures associated with each plant system.

Purification Technology Determine the potential value of high-temperature filtration devices and the effect of increased flow in the low-temperature purification system.

Training Programs Develop training programs in the chemistry and health-physics area and make these available to utility personnel. Using cost-benefit techniques, establish the importance of proper chemistry and lower plant radiation levels.

Decontamination Develop short-term, low-concentration decontamination techniques for both PWRs and BWRs. In addition, develop improved methods to decontaminate individual fuel assemblies during a refueling.

The above summary of the workshop recommendations does not imply that EPRI will support each of these recommendations. The nine summary recommendations were not assigned priorities by the workshop but have been submitted by EPRI to subcommittees within the National Association of Corrosion Engineers and the American Society of Mechanical Engineers for such assignment, which will be used by EPRI only as a guideline in establishing its future research activities.

Discussions following the workshop presentations are the basis for the following general comments.

□ The technical personnel expressed the need for utility management to appreciate the importance of chemistry and health-physics functions in the successful operation of nuclear plants.

□ The attendees expressed the need for individual utilities to assume a larger role than they presently play in obtaining data on the areas of research recommended in the workshop.

□ The workshop attendees would like to see EPRI involved in developing training programs for utility personnel and in establishing central data storage and retrieval systems for utility-collected data as a recognized objective of R&D programs.

□ The attendees agreed that the greatest returns on efforts to lower radiation levels can be obtained during the design stage of a nuclear power plant. Therefore, there was strong support for individual utilities to establish a radiation design audit team for the review of auxiliary systems before the final design is accepted.

Copies of *Proceedings of the System Contamination Workshop* have been distributed to the attendees; additional copies can be obtained from the workshop directors by contacting them at EPRI. *Project Managers: D. L. Uhl, R. A. Shaw*

REACTOR RECIRCULATION PUMP PERFORMANCE UNDER TWO-PHASE FLOW CONDITIONS

Large recirculation pumps are used in LWRs to move the coolant through the system. During normal operating conditions, the water entering the pumps is subcooled, thus allowing the pump to operate at its design point with single-phase flow. As part of the routine licensing analyses, the NRC requires the consideration of the consequences of a hypothetical LOCA with the discharge of coolant from a double-ended guillotine break of the largest system pipe. One of the questions arising as a consequence of this postulated LOCA is: How do the recirculation pumps in both the broken and unbroken loops perform during the time period of interest subsequent to the assumed break?

Present LOCA calculations are forced to assume a conservative mathematical modeling of the pump due to the absence of applicable large-scale experimental data to substantiate a more realistic performance model. There are two major concerns relating to the LOCA performance of reactor pumps. The first relates to how the pumps perform in providing coolant flow to the reactor core during depressurization, and the second concerns the possibility of the pump overspeeding due to rapid blowdown through the pump and out through the break. In an attempt to alleviate these concerns, EPRI is funding four projects, each of which is discussed briefly below.

A large-scale pump test project is being performed at Combustion Engineering, Inc. (C-E) with a geometrically scaled model reactor pump. In support of that project, Creare Inc. is performing small-scale pump modeling to improve the phenomenological understanding of pump two-phase performance, and the Massachusetts Institute of Technology (MIT) is evaluating and attempting to improve existing pump two-phase flow analytic models. The fourth project, with Babcock & Wilcox Co. (B&W), involves large-scale pump tests, analytic modeling, and application of data and analysis to LWR LOCA conditions.

The C-E–EPRI two-phase pump performance project will test a 1/5-scale reactor recirculation pump in steam-water flow for steady-state, four-quadrant conditions and for transient blowdown conditions (RP301). The objectives are to obtain sufficient steady-state and transient two-phase performance data to substantiate, and ultimately improve, the mathematical model of recirculation pumps presently used for LOCA analysis. Data on pump overspeed characteristics under transient two-phase blowdown conditions will also be collected and analyzed.

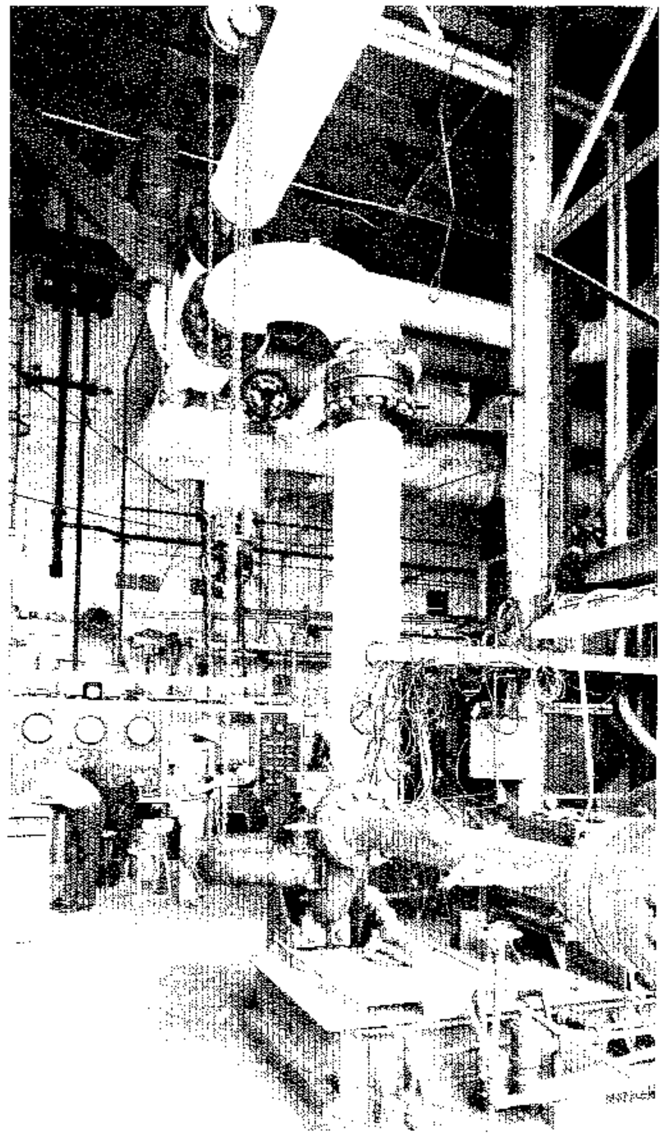


Figure 1 C-E Pump Test Facility under construction. Test pump in lower center.

The model pump is mounted in a test loop capable of providing steam-water operating conditions typical of those encountered in LWRs during postulated LOCA events. The test pump is of the mixed-flow type with a specific speed of 4200 rpm. The rated peak efficiency values of performance

Figure 2 Two-phase pump projects schedule.

for cold water are: head = 252 ft; flow = 3500 gpm; speed = 4500 rpm; torque = 308 ft-lb at 62.4 lbm/ft^3 density.

Pump performance is generally measured and described in terms of head and torque for a given speed, volume flow rate, and fluid density. For two-phase flow, the fluid density and the phase behavior are related not only to pressure and/or temperature but also to void fraction and phase distribution (also known as flow regime). For transient blowdown tests, there is the additional aspect of indicating how rapidly the hydraulic parameters change with time. The main index to the severity of blowdown transients chosen for this project is the rate of change in two-phase mixture as expressed by the average pump void fraction versus time (*1*).

The current status of this project is that the test facility has been completed and all instrumentation has been installed. Loop shakedown and instrument calibration have been completed. Testing is scheduled to start in early August 1976.

The Creare project (RP347, Task A) is oriented toward the phenomenological understanding and modeling of pumps under LOCA-type conditions. Specific objectives are to define the fluid dynamic and mechanical characteristics of LWR recirculation piping and pumps important to LWR safety analysis and to determine the adequacy of scale-model testing in this context to understand prototypical behavior.

Small-scale (about 1/20) testing of typical reactor recirculation pumps will be conducted both at low and at high pressures. The advantages of modeling pump and surrounding piping at a low pressure is that transparent piping can be used, which allows the flow regime and other fluid dynamic characteristics to be observed visually. Both the C-E 1/5-scale test loop and pump and the B&W 1/3-scale test (see below) will be modeled at about 1/20 scale. These model tests are expected to give valuable information on the applicability of data from small-scale tests in predicting large-scale component behavior. By using transparent pump housing, attempts will be made to study the fluid behavior inside the pump. Another point of interest that will be evaluated in this project is how steam-water and air-water performances compare for the same test system.

A review and analysis of two-phase pump technology (*2*) has been completed. Low-pressure flow regime studies in both the C-E and B&W transparent piping models have been conducted, using both air-water and Freon-water two-phase flow. The latter two-component, two-phase mixture was used because it has the same density ratio between gas and liquid at low pressures as steam-water at high pressures. The gas-liquid density ratio is believed to be an important parameter when two-phase flow is studied, particularly in the formation of various flow regimes. Analysis of these data is currently underway. The C-E 1/20-scale model pump is being tested simultaneously.

The MIT basic investigation of two-phase pump performance (RP493) is oriented toward analytic modeling of pumps under two-phase flow conditions in forward and reverse rotation and flow. Interaction with the other projects and utilization of existing and forthcoming data in the model development are planned.

Different flow regime conditions and onset of cavitation in the flow will be investigated. The state-of-the-art review has been completed, and currently various analytic methods are being evaluated and applied to existing data to approximate two-phase pump performance in a computer model.

The B&W project on model pump tests and analysis for LOCA application (RP498) is oriented toward LOCA analysis code work related to pump behavior. Experimental data from a 1/3-scale pump air-water test program will be analyzed and the results applied to develop a two-phase homologous curve performance model for inclusion in LOCA analysis codes. A best-estimate-type code, with the developed pump model incorporated, will then be used to determine more realistic peak clad temperatures and pump overspeed under LOCA conditions. An evaluation of the applicability of steady-state, two-phase flow pump performance curves to predict transient two-phase pump performance will also be made.

The results of the 1/3-scale air-water pump model tests have been reported. Analysis and correlation of the data are currently being performed to design by computer a pump model for use in the LOCA analysis mentioned above.

It is hoped that the large-scale pump tests performed at C-E and B&W will substantially improve the understanding of pump behavior under two-phase flow conditions. The C-E large-scale pump model testing, as well as Creare's small-scale work, is aimed at improving the understanding of scaling laws and how small-scale model data can be applied to evaluate the performance of larger units. The data from Creare on the C-E 1/20-scale model pump in steam-water and air-water flows plus similar data on the B&W small-scale model pump should permit a clear examination of the differences, if any, due to changes in flow composition. As a result of this effort, it is hoped that an improved understanding of pump two-phase flow performance will be achieved and that an acceptable analytic model can be designed and used in LOCA analysis codes.

The current time schedule for these projects is presented in Figure 2. All four projects were started during 1975, and the total two-phase pump program is scheduled for completion in early 1978. *Project Manager: K. A. Nilsson*

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R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

SULFUR OXIDE CONTROL

The control of sulfur oxide emissions has become a focal issue in the use of coal as a primary utility boiler fuel. As a result of air quality emission standards set by EPA and numerous state and local regulatory bodies, flue gas desulfurization (FGD) processes are being installed at many utility power stations. As of January 1976, there were 21 operational utility FGD systems, 20 units under construction, and 67 units planned. This represents a capacity of 40,000 MW and a financial commitment by the utility industry of more than $4 billion.

Sulfur dioxide removal processes are generally classified as either throwaway (nonregenerable) or recovery (regenerable) systems. Throwaway processes, such as lime-limestone and double alkali scrubbing, convert the sulfur dioxide to a waste by-product. Scrubbing with lime or limestone slurry is used in more than three-fourths of the operational FGD systems. Recovery processes produce sulfur or sulfuric acid in a useful, salable form. These relatively complex, expensive processes are now evolving beyond the pilot scale to larger, prototype demonstration facilities.

Even though lime-limestone scrubbing technology is being applied by the utility industry to control sulfur dioxide emissions, numerous improvements are required before these processes can be operated with a high degree of confidence in their efficiency and reliability. Therefore, the thrust of the EPRI program is to develop a sound basis for designing and operating lime-limestone scrubbing processes for a range of site-specific conditions.

The EPRI program for regenerable processes focuses on a series of competitive design and evaluation studies that may lead to the selection of one or two processes for prototype testing.

Lime-Limestone Scrubbing

To assist EPRI in defining specific problem areas in lime-limestone scrubbing, Battelle, Columbus Laboratories and Slack Advisory Services were contracted to assess the state of the art in stack gas scrubbing. It was concluded that while the basic technology for SO_2 removal exists, the major remaining problem is the demonstration of continuous, long-term process reliability. Specific problem areas limiting long-term process reliability that were identified for further study include:

- Mist eliminator reliability
- Stack gas reheat
- Equipment corrosion and erosion
- Waste solids dewatering and disposal
- Characterization of process chemistry for various absorbents, coal types, and scrubber operating conditions

Many lime-limestone scrubber failures are related to plugging and scaling of the mist eliminator. The mechanical design of the demister (chevron, baffle, radial vane, etc.) affects the efficiency of the device to remove entrained liquid droplets from the scrubber. However, demister configuration (horizontal, vertical, or inclined) and the degree and frequency of washing with fresh or recycle water are controlling factors in the plugging potential of the demister. Recent results from the TVA–EPA Shawnee pilot scrubbing facility have indicated the tendency of the demister to remain clean when there is a high degree of alkali utilization in the scrubber. It is also generally accepted that the wash water should be of the highest quality available to the system. A recent unit study on mist eliminator design by Battelle, Columbus Laboratories (RP209-1) summarizes current demister operating experience and design alternatives for improving present reliability.

Stack gas reheat is applied after wet scrubbers to avoid downstream condensation and corrosion in the fan, ductwork, and stack; to avoid a visible plume; and to improve plume rise and dispersion. Types of reheat systems currently being employed include in-line reheat (steam or hot water tubes in the exit flue gas duct), indirect hot air reheat (steam-coil-heated ambient air blended with the scrubber exit gases), and direct combustion of natural gas or fuel oil.

Another recently completed study by Battelle for EPRI concluded that the least energy requirement to avoid downstream condensation can be obtained by an in-line reheater; however, corrosion of the tubes has been a problem. Based on this experience, the Tennessee Valley Authority (TVA) is evaluating the corrosion resistance of a number of reheat tube materials in an EPRI-supported pilot study at the Colbert pilot plant. On the other hand, the least energy requirement to avoid a visible plume can be obtained by an indirect hot air reheater. This design also results in a higher plume rise and improved pollutant dispersion due to the effect of dilution air. Indirect hot air reheaters are more capital-intensive than other designs but have lower maintenance costs due to the absence of corrosion and plugging. TVA is also evaluating two improved reheater designs that could reduce energy costs.

The pilot testing program by TVA also includes an evaluation of materials of construction for lime-limestone scrubber components to minimize the effects of corrosion and erosion by the abrasive slurry. This test work, when correlated with the large amount of available full-scale scrubber operating experience, should provide guidelines for selection of pumps, valves, and nozzle construction materials.

The dewatering and disposal of solid wastes from SO_2 scrubbing systems present unique problems to design engineers. Depending on fuel type and boiler and scrubber operating conditions, the waste sludge composition and resultant dewatering characteristics can be highly variable. Typically, FGD sludge is a mixture of fly ash, calcium sulfate, calcium sulfite, unreacted absorbent, minor alkali species, and water. An initial EPRI project with TVA is designed to establish the relationship between the physical and the chemical characteristics of scrubber sludge and full-scale scrubber and boiler operating conditions. This, coupled with the project being initiated under RP786, By-product/Waste Disposal From Flue Gas Cleaning Processes, is intended to result in guidelines for predicting the handling and fixation properties of various sludges.

The trace elements entering the generating station in the coal will leave the station primarily in the ash and scrubber sludge. Coal wastes are commonly disposed of by ponding. A recently completed study by Southern California Edison Co. and Radian Corp. under EPRI support addressed the problem of potential leaching of trace elements from ponded ash and scrubber sludge into the ground. Based on laboratory tests to simulate leaching conditions on samples of ash and sludge, it was found that only selenium, chromium, boron, and in isolated instances,mercury and barium exceeded the proposed EPA Public Water Supply Guidelines. It was also found that passage of pond effluent through soil can provide significant protection against groundwater contamination by these trace elements.

A most important area of future study for lime-limestone FGD processes is the characterization of process chemistry for various absorbents, coal types, and scrubber operating conditions. Vital to this characterization is an understanding of the oxidation of sulfite to sulfate and its impact on scrubber design. EPRI projects currently being planned and initiated will address these issues.

Regenerable Processes

Recognizing the need to develop FGD processes that (1) do not create a solid waste disposal problem, (2) are not dependent on limestone raw materials, (3) offer the potential of being less sensitive to site-specific design variables, and (4) can produce a usable by-product in the form of elemental sulfur or sulfuric acid, EPRI is also active in the evaluation of regenerable processes. These efforts consider not only development of new processes in the utility context but also improvements to processes for which the industry has already made development and demonstration commitments.

The objective of a recently completed EPRI study by Radian Corp. (RP535) was to provide a comparative state-of-the-art evaluation of eight advanced regenerable FGD processes on a common design and cost basis, to assess their future potential, and to make recommendations on the level of additional developmental activities. These were compared with three first-generation regenerable FGD processes (Mag-Ox, Wellman Lord, and Cat-Ox), as well as lime-limestone scrubbing processes. Five evaluation criteria were used: environmental effects, raw material and utility requirements, development status, unique design features, and special technical and economic problems. The study reached the following general conclusions:

□ Although capital costs cannot be explicitly defined with confidence at this time, it is clear that this factor will represent the major cost item in the total annualized cost of these advanced processes. In addition, raw material and utility costs for the advanced regenerable processes range from 1.2 to 4.0 mills/kWh. In general, the "dry" advanced FGD processes, such as the Shell/UOP, Westvaco, and Bergbau-Forschung/Foster-Wheeler, were found to have higher raw material and utility costs than the "wet" processes, such as the Atomics International, Catalytic/IFP, Citrate/Phosphate, and TVA Ammonia-ABS.

□ From a technical feasibility standpoint, design and operating problems for dry processes have been primarily mechanical in nature, whereas the problems for wet processes have been more chemical in nature. The adequacy of available design and operating data for these processes suggests that successful operation on a prototype (20–40 MW) scale should precede commercial scale (100 MW) application.

Although they appear to be technically feasible, the advanced FGD processes may encounter acceptance problems because much of the chemical technology used is foreign to the utility industry. This issue has been generally underestimated in the rush to commercial-scale utility demonstration of the earlier regenerable processes. As a result, it should be considered premature to reject systems such as Mag-Ox or Wellman Lord in favor of the more advanced regenerable FGD processes until sufficient operating experience has been achieved on these existing utility demonstration facilities.

□ Since some regenerable processes are better suited for sulfur production and others are better suited for sulfuric acid production, site-specific studies of sulfur, sulfuric acid, and gypsum marketability should be conducted by a utility in selecting a specific regenerable process for its local condition. An ongoing TVA study on potential by-product marketing should provide an improved basis for these decisions.

□ Some processes require significant hydrogen–carbon-monoxide reducing gas if they are to produce elemental sulfur. If this H_2CO reducing gas must be derived from coal or heavy oil instead of natural gas, the process is penalized both technically and economically. This may lead to the selection of sulfuric acid rather than elemental sulfur as the economically preferred by-product. Further study of process chemistry interferences resulting from trace contaminants in the H_2CO reducing gas is needed to minimize the technical liabilities.

Using the comparative process analysis by Radian as a basis, EPRI initiated a detailed design and competitive evaluation project for advanced regenerable processes that may lead to the selection of one or two processes for prototype plant (20–40 MW) construction and demonstration. Project objectives include (1) performance of detailed integrated designs of several attractive regenerable FGD processes for a specific host utility site by the system supplier in conjunction with an architect-engineering firm and (2) evaluation of capital costs, level of process development for prototype construction, and applicability of processes over a wide range of utility operating conditions.

Further Efforts

A major part of the EPRI program in SO_2 control consists of collecting and evaluating the large amount of available operating data for lime-limestone scrubbing and formulating design guidelines for improving process reliability. Where specific gaps in the data base can be identified, appropriate bench, pilot, or full-scale development and test support is warranted.

Until sufficient development and operating experience has been translated into reliable guidelines for site-specific design and operation, flue gas desulfurization processes should be regarded in the utility context as experimental demonstrations and staffed and budgeted for maintenance-intensive operation. Once these guidelines have been developed, they will provide a basis for the utilities to encourage system suppliers to assemble a control system that incorporates the best components (i.e., absorber, mist eliminator, reheater, process equipment) of all presently available scrubber systems. Once the hardware has reached a reasonable level of reliability and standardization, major attention can be given to optimizing site-specific process chemistry. *Program Manager: Kurt Yeager*

GEOTHERMAL PROGRAM

Geothermal energy is regionally distributed, but there is also a multiplicity of resource types, as well as site-to-site variability of geologic, chemical, physical, and thermodynamic characteristics. As one might expect, these characteristics cause considerable uncertainty about commercial viability. The resource types are usually categorized as follows:

- □ Hydrothermal Convection Systems
  - Vapor dominated (dry steam)
  - Hot water dominated
    - Low salinity
    - High salinity
- □ Geopressured Systems
- □ Hot Igneous Systems
  - Crystallized rock (wet or dry)
  - Magma
- □ Normal Gradient

Hydrothermal Resources

Although hydrothermal resources represent only about 4% of the heat and perhaps 10% of the convertible geothermal energy, this resource type is of greatest interest to the utilities in the near and intermediate terms for several reasons. Power plants now in operation at the Geysers in California and in other countries have demonstrated that present dry steam and flashed steam technology is generally adequate for the development of clean, high-temperature resources where surface disposal of the spent geothermal fluids has been possible. Reinjection of spent fluids has not been demonstrated on a large scale. Furthermore, it is usually assumed that the lower-grade hydrothermal resources can be developed by adaptations of present technology. This assumption appears to be fundamentally correct, but a great deal of work remains to determine the sets of technology best suited for each of the various resource subtypes. Innovation or modification of the technology will be necessary for some of these resource subtypes, and although development may be technically feasible, economic feasibility must also be demonstrated before commercial applications can be achieved.

While hydrothermal resources are relatively small in comparison to total geothermal resources, their contribution to electric power generation could be significant. The contribution is expected to be somewhere in the range of 12,000 MWe × 30 years (present reserve) to 130,000 MWe × 30 years (upper estimate by USGS). It also seems likely that the conversion technology developed by hydrothermal resources will have application to the hot water component of geopressure resources and may have application as first-generation technology in the development of hot igneous systems when these resources become available for commercial development. For these reasons, the next logical step in the orderly development of geothermal energy is the development of the hydrothermal resources in the U.S.

How important will hydrothermal resources be to the utility industry? The present reserves (12,000 MWe × 30 years) are interesting on a regional and local basis, and there is a need for additional baseload capacity to supplement other energy sources. On a broader basis, any new energy sources would be expected to have a net favorable impact on energy supplies, and as the hydrothermal generating capacity increases, the competition for other energy sources in nongeothermal regions might be reduced. Although it is too early to know the exact importance of geothermal energy to the utility industry at this time, it is clear that the development of hydrothermal systems is critically important to an assessment of the overall importance of geothermal resources and can add generating capacity in the near term.

Low-Salinity Hydrothermal Demonstration Plant Subprogram

The largest effort in the EPRI program at this time is the low-salinity hydrothermal demonstration plant subprogram. EPRI contracted with the joint venture team of Holt/Procon in October 1975 for a one-year feasibility study. This study is viewed as the first phase of a multiyear effort that will culminate in the construction of a 25–50 MWe hydrothermal power plant early in 1980, providing feasibility is established. The objective of the first phase is to assess the technical, economic, and environmental feasibility and to select a site for the demonstration plant. The overall objectives of the project are: (1) to confirm that current technology can be successfully adapted to low-salinity, moderate temperature hydrothermal systems, including environmental impact control; (2) to demonstrate economic viability and environmental acceptance of a commercial-size hydrothermal power plant; and (3) to develop an experience base that can be extrapolated to a large portion of all hydrothermal resources. The project is also expected to help determine what portion of our hydrothermal resources have commercial potential with current technology. It will also help to verify reservoir development techniques. It is planned that funding for the project will be provided by EPRI, the participating utilities, the resource companies, and possibly ERDA. EPRI's share is expected to be about 10% of the total project cost.

Feasibility implies that a number of technical criteria are met. The major criteria are as follows:

- The selected site is representative of other hydrothermal fields.
- The reservoir analysis justifies reasonably high confidence that the reservoir will produce as expected and has commercial potential beyond 50 MWe.
- The power conversion system will perform with a high degree of reliability and availability.
- Environmental standards can be adequately met.
- The economics are competitive.

The first part of the study, technical feasibility analysis, is now complete.

Site Selection Considerations At the outset of the study, two reservoirs were considered sufficiently well defined to be considered as primary candidates. These were Heber in the Imperial Valley of California and Valles Caldera in New Mexico. To gain some insight into which of the candidate reservoirs might be more representative of the hydrothermal class, 16 reservoirs were selected for study—all of which have salinity less than seawater and temperatures of 150°C or higher. Because of the meagerness of the data for some of the reservoirs, the list was subsequently reduced to 10. These reservoirs are compared in Table 1.

The sample size is small and probably skewed toward the hotter reservoirs; however, some trends are apparent. For example, the data appear to cluster closer for the young volcanic systems than for the sedimentary. The young volcanic systems are hotter and contain more energy. There are more sedimentary than young volcanic systems and the data for these sedimentary systems tend to be more scattered, while the depths of most of the systems are similar.

Considering all factors, the Heber site appears to have the best qualifications as a demonstration site for the EPRI project. The Heber temperature is closest to the average, and although its salinity is higher than average, any system that can handle the Heber brine should be capable of handling lower salinities with less maintenance. Heber appears to be more representative of roughly 80% of the identified hydrothermal reservoirs and has 40–50% of the recoverable energy in these reservoirs. The reservoir analysis indicates that the Heber field can support at least 220 MWe for 30 years. The Chevron Oil Co. cooperated closely with EPRI in the reservoir engineering study and shared the data from the field with the project staff.

Power Conversion Binary-cycle and flashed-steam conversion processes are two technologies that are sufficiently mature to be considered for use in this project. A dual-cycle hybrid of these two was also considered, but its technology is the same. Binary, flashed steam, and hybrid were studied, and the performance of each was analyzed for each of three reservoir types—including Raft River (150°C), Heber (190°C), and Valles Caldera (240°C). The preliminary conclusions were that the binary cycle has certain advantages. The first is that

Table 1
RESERVOIR COMPARISON

	Temp (°C)	Heat Content (10^{18} Cal)	Elec Power Potential (MWe/C)	Salinity (ppm)	Flow Test (gpm)	Nominal Depth (ft)
Sedimentary						
Roosevelt Hot Springs, Utah	230	1.2	33	7,000	1,400	3,000
Brady Hot Springs, Nevada	214	4.5	119	2,500	120	5,000
Heber, California	190	11	292	15,000	450	5,000
East Mesa, California	180	5.5	146	20,000	460	6,000
Surprise Valley, California	175	24	637	1,500	–	6,000
Raft River, Idaho	150	--	--	2,000	900	5,000
Young Volcanic						
Valles Caldera, New Mexico	240	18	597	5,000	900	6,000
Beowawe, Nevada	240	5.7	189	1,200	1,000	7,000
Long Valley, California	220	55	1825	1,500	1,000	1,000
Coso Hot Springs, California	220	41	1360	4,000	40	500

Table 2
ESTIMATED GEOTHERMAL POWER COST—HEBER

	Brine Rate thousand lb/hr	Fuel Cost		Power Cost (mills/kWh)				
		¢/thousand lb brine	¢/million Btu	Fuel	Fixed Charges	Operation and Maintenance	Transmission	Total
Binary	6,942	12.0	57.5	16.69	15.03	3.22	0.28	35.22
Flashed Steam	10,010	10.3	71.7	20.53	14.13	3.14	0.28	38.08
Hybrid	7,248	11.9	60.2	17.26	19.30	3.65	0.28	40.49

while the Rankine-cycle efficiency is somewhat less than that for steam, it requires less brine per kilowatt hour. Second, noncondensable gases have little effect on the net power out. From the standpoint of purely technical feasibility, it appears that any one of these three conversion processes might be considered if adequate consideration is given to heat exchanger performance and hydrocarbon turbine scale-up in conjunction with the binary systems and to low-pressure steam turbines in conjunction with the lower-temperature systems. Cost is considered separately.

Economic Feasibility Costs were estimated for each of the nine cases discussed above. The preliminary results for the Heber site are given in Table 2. The power costs are for 1980. and it should be noted that the fuel cost estimates were prepared by the contractor and not by the resource companies, but the two estimates were very close. The final fuel price must be negotiated by the utilities and the resource companies. However, the results of this analysis are thought to be sufficiently accurate for use in the preliminary assessment of economic feasibility. On this basis, the power costs appear to be in a competitive range with other energy sources. For minimum power costs, it appears that the binary cycle would be the best choice for Heber.

Environmental Considerations Cooling water availability, subsidence, induced seismicity, water quality, and air quality are of special interest when considered in conjunction with geothermal production. Geothermal power plants must reject more heat than conventional power plants. In the Imperial Valley, where Heber is located, some small quantities of fresh irrigation water will be available for geothermal development but would probably not continue through the life of a plant. The primary alternative is to use agricultural waste water. There is a limit to how much of the agricultural waste water could be recycled through geothermal power plants, however. It might be expected to support several hundred, or even a few thousand megawatts, but it is not expected to be sufficient to support full geothermal development of the Imperial Valley.

Subsidence is of particular concern in certain areas, such as those with high populations, gravity flow irrigation systems, or flood susceptibility. The only known preventive to subsidence is the simultaneous reinjection of fluids into the formation. With reinjection, subsidence is not expected to be a problem at the Heber field. For example, the natural rate of subsidence in the Imperial Valley ranges from a few millimeters to over 5 cm, whereas the amount of subsidence induced by withdrawing and reinjecting geothermal fluid, combined with the minor thermal contraction that might result if the reservoir cools, is estimated to be less than the present natural rate of subsidence.

The greatest effect from induced seismicity has been observed in areas where the overpressures are high over a large portion of a reservoir. These conditions are not expected, and although there is some remote possibility of inducing seismic activity, the magnitude would probably be insignificant, particularly in the Heber field. It also appears possible to differentiate between natural and induced seismic events so that this phenomenon can be accurately monitored.

The effect on surface water quality can be controlled by reinjection. Air quality is not a problem where noncondensable gases are not allowed to escape and where the amount of offensive noncondensable gases is very small.

Research and Technology Development Subprogram

Brine Chemistry and Heat-Mass Transfer In December 1975 EPRI awarded a contract to Battelle, Northwest Laboratories for research in the area of brine chemistry and heat-mass transfer (RP653). This project is to identify and quantify the effects of site-to-site variability on geothermal power plant design criteria. Relatively wide variations in physical, chemical, and thermodynamic properties of geothermal brines exist at different reservoirs, and there is apparent variability from site to site within the same reservoirs. The variability of geothermal brines complicates the power plant design problem and can impact commercial feasibility. The initial effort will include three areas of investigation: (1) brine chemistry data base development; (2) chemical kinetics and heat-mass transfer experiments to determine rates and their effect on scaling, corrosion and erosion; and (3) development of a systems analysis capability for analytic treatment of the degradation of geothermal fluid loops within geothermal power plants. This capability will be useful in estimating performance degradation and equipment life. These, in turn, will assist in developing maintenance philosophy, schedules, procedures, and costs.

Mobile Geothermal Fluids, Materials, and Components Test System Contract negotiations have been initiated for this project and the contract award is expected shortly. The objective of the project is to design, fabricate, test, and operate a mobile test system that will provide the capability for a quick turn-around, low-cost, standard analysis of geothermal fluids at different sites. It will also provide the capability to test new items of equipment with different geothermal brines. It is expected to contribute to the development of the site-to-site variability data base and should help utilities in the early assessment of the commercial potential of individual wells and reservoirs. *Program Manager: Vasel W. Roberts*

MATERIALS FOR COAL CONVERSION PROCESSES

Materials will be a limiting factor in most of the new technologies being developed to burn coal or to convert coal to a clean fuel. Several kinds of chemical interactions will occur between the structural components and the high-temperature, highly reactive gases of those new processes. Moreover, the process gases will carry small particles of coal ash, uncombusted coal, and other process constituents. We believe the combination of erosion and corrosion will lead to accelerated degradation of structural materials. Therefore, a significant portion of our research projects is devoted to this topic. Similarly, long-term behavior of materials under the mechanical loads, high temperatures, and hydrogenous atmospheres of coal-conversion pressure vessels is a major concern in our program.

Materials Design for Erosion-Corrosion Service

Most of the materials presently used to resist high-temperature erosion-corrosion conditions are probably not optimal. In addition, we feel that sufficient attention has not been paid to modern alloy design practice. Most of the alloys now in use were developed for other purposes, generally for operation in strongly oxidizing environments where surface oxides protect the underlying metal during service. In contrast, many of the new technologies are characterized by low oxygen partial pressures, on the order of 10^{-10} atm. This means that adequate surface oxides may not be generated to protect against other reactions, such as carburization and sulfidation of certain alloy constituents. Also, the erosive conditions in gasifier internals, transfer lines, valves and separators, fluidized-bed boilers, and gas turbines indicate that any protective oxide scales may be eroded and that wastage under the combined erosion-corrosion may be worse than under corrosion alone.

An important first step is to assemble the known information about high-temperature oxidation and corrosion in electric generating systems. Although experience with materials deterioration in fossil-fuel-fired systems is very extensive, this information is dispersed in a wide range of scientific and technical literature, in governmental and other reports, as well as contained in unpublished experience within utilities. Collecting this information in one record will provide a guide for selecting materials for new systems and will identify critical research issues. Battelle, Columbus Laboratories and the University of Liverpool have been selected to assemble the data record (RP538). This 18-month project will use as a point of departure the 600-page data record on high-temperature corrosion of gas turbine alloys that Professor John Stringer of the University of Liverpool prepared for NATO. The NATO document covers pertinent equilibrium diagrams and diffusion data for materials in oxidizing conditions.

Lockheed Palo Alto Research Laboratory will investigate the corrosion chemistry of alloys in low-oxygen-activity atmospheres (RP716). The project seeks fundamental information about the corrosion reactions in coal conversion and combustion environments that contain several reactive species, such as oxygen, sulfur, carbon, and nitrogen. Of special interest are conditions in which these constituents are near product-phase stability limits, in which case small fluctuations in temperature, pressure, or gas composition can cause local regions of metallic systems to cycle between two alternately stable products. Several accelerated corrosions are recognized hazards: repeated interchange between carburization and oxidation gives rise to a degradation known as *green rot;* cyclic sulfidation and oxidation have been termed *black plague;* rapid grain-boundary carburization under ruptures in an oxide film is termed *metal dusting.* Model alloys as well as commercial materials will be studied in several well-defined environments. Lockheed's efforts will be supplemented by a supporting contract with Ohio State University.

The balance of the program is made up of four alloy design projects that will first determine the failure mechanisms under the pertinent services, relate alloy composition and structure to the design property involved in the failure mechanism, and then adjust the compositions and structures to suppress the identified failure modes. Each of the four projects will issue a report on the state of the art and science in its particular research topic. These will be assembled in a single set of reports at the start of the erosion-corrosion program.

A project with Foster Wheeler Energy Corp. and the International Nickel Co. (RP644) is aimed at improved materials systems for coal-fired superheater and reheater tubes. Both fireside and steamside corrosion will be investigated. There are now a number of new alloy candidates that are ready for evaluation as boiler tubes in the hope of reducing boiler tube wastage. Also, we expect that the alloy design methodology will uncover new approaches for better alloy compositions and for surface treatment of existing boiler tube alloys. The most troublesome problem in steamside corrosion of superheater and reheater tubes is that detachment or exfoliation of scale causes erosion downstream in the steam turbine. Although an unscheduled outage from erosion is usually ascribed to the turbine, the underlying reason for failures may be in the boiler. Among the approaches that we hope will alleviate exfoliation are the use of alloying additions such as rare earth metals to improve scale adherence; surface treatments that will encourage growth of adherent rather than spalling oxide scales; and various protective diffusion coatings of aluminum, chromium silicon, and nickel. Fireside corrosion involves attack by alkali sulfates, chlorides, and combined carburization-oxidation. The appropriate environmental regimes for each will be identified through the use of model alloys. A large series of state-of-the-art and advanced alloys will be evaluated for corrosion resistance, cladding, and coating approaches.

In another project Battelle, Columbus Laboratories and the Stellite Division of Cabot Corp. are designing alloys for use at high temperatures in high-density, low-velocity particle erosion, under both oxidizing and reducing conditions characteristic of coal gasifiers and fluidized-bed combustors (RP589). The aim of the project is to determine the effects of alloy variables, such as microstructure and composition, on the resistance of a material to erosion-corrosion. Major emphasis is being given to alloy design from the best state-of-the-art alloys as the point of departure. The fundamentals of erosion, in terms of particle size, velocity, impingement angle, and temperature, as well as the simultaneous corrosive effects of variations in gas composition and condensed salt layers, will be studied in a special erosion-corrosion test apparatus that has been built for this project.

A parallel project for refractory design has been initiated with Westinghouse Corp. (RP625). This project will study erosion-corrosion of refractories under both dry ash and slagging devices. The amount of slag on the refractory lining may be a limiting design aspect of the systems. Another design limitation that will be given special attention is frequent thermal cycling (such as occurs in load following), which is known to accelerate refractory failure.

Design of alloys and coatings to be used under erosive-corrosive conditions in gas turbines is the subject of a project with Pratt and Whitney Aircraft (RP543). Of interest are the environmental conditions in expander turbines for gasifiers and fluidized-bed combustors, as well as in combustion turbines that use coal or coal-derived fuels. It is anticipated that the gases entering the turbines will be cleaned to the maximum extent possible, but some residual gaseous and particulate contamination is unavoidable. Thus, we are concerned with low-density, high-velocity particle erosion. The materials in the Pratt and Whitney study are the best state-of-the-art materials used in modern aircraft gas turbine practice. The means by which these fail in the hot corrosion-erosion burner test apparatus will provide a basis for designing improved alloys and coatings.

Improved Steels for Pressure Vessel Service

Processes that produce synthetic hydrocarbons from coal typically take place within steel pressure vessels that operate at high pressures and temperatures. Continuous, safe, and reliable operation of these vessels is vital for successful coal conversion processes on an industrial scale. The basic problem not only concerns high pressures and temperatures but also the highly reactive hydrogen-containing environments. The ability to select economical steels for construction of pressure vessels will depend on a complete understanding of the responsible failure mechanisms. We must also develop useful life predictions and operation criteria for pressure vessels and, possibly, improved low-cost steels for pressure vessel service.

Even in the absence of corrosive atmospheres, metals and alloys fail under load at high temperatures through atomic mechanisms (called creep) that result in very slow accumulations of strain. In addition to the obvious need for creep rupture test data on steels used in the power industries, there is an equally compelling need for extrapolating these data to long times (10–30 years, or more). A project with the Metal Properties Council (RP638) is aimed at developing a standard time-temperature parameter to satisfy that need. The objectives of the research are (1) to prepare a recommended practice statement for a new technique (devised in the NASA program) for the extrapolation of creep rupture data, (2) to seek a consensus on the method through evaluations from potential users, (3) to refine the technique by testing it against long-time data collected from worldwide sources, and (4) to activate research in the factors that govern alloy stability.

Another severe constraint on the use of low-alloy steels in steam plant and coal conversion equipment is imposed by the tendency of residual impurities in the steel to segregate to internal boundaries between the crystals, or grains, that make up the bulk material. This reduces toughness at ordinary temperatures and enhances brittle intergranular fractures at elevated temperatures. Furthermore, it has been predicted that such segregation will also increase the susceptibility of the material to cracking in media such as hydrogen or caustic aqueous solutions. A two-year project with the University of Pennsylvania (RP559) is intended to provide the technology required to minimize the risk of component failures arising from metal grain-boundary embrittling phenomena, called temper embrittlement. Embrittlement diagrams will be generated for steel types of interest to the utility industry, especially those used in pressure vessels and large turbine rotors. Changes in mechanical properties that result from metalloid segregation will be studied by doping the pertinent steels with metalloid concentrations in the parts-per-million range. In addition, the influence of microstructure and hardness on embrittlement kinetics will be determined. A knowledge of the relationships of these parameters will permit predictions of susceptibility to temper embrittlement. A further phase of the project will identify the effects of impurity segregation on creep strength and ductility at elevated temperatures. Major progress can already be seen in the recent University of Pennsylvania corroboration of the prediction that temper embrittlement facilitates hydrogen-assisted crack growth.

It is known that interactions between hydrogen-rich gases and steels can cause significant reductions in mechanical integrity of the metal through corrosion, hydrogen embrittlement, and hydrogen attack, depending on the steel properties and the exact service conditions. Given no other complications, we know from experience what the thresholds for hydrogen attack are in terms of hydrogen pressure, temperatures, and steel compositions. However, it must be appreciated that large, welded pressure vessels, particularly those with complex geometries, will contain some defects by virtue of the manufacturing methods. The size of the defects initially present depends in part on the capabilities (and limitations) of the inspection and evaluation procedures used for quality ensurance of the fabricated vessel. Unfortunately, virtually nothing is known about the interaction of preexisting flaws with the combined hydrogenous-corrosive environments typical of coal conversion processes. Thus, the dependence of subcritical crack growth on stress, temperature, gas composition, gas pressure, and time will be evaluated in a project with Westinghouse Electric Corp. (RP627). Measurements will be made on the steel selected for the most extreme pressure vessel service (coal liquefaction) and on a stainless steel, weld-overlay–baseplate combination. Pending these results, we plan to extend this study to other pressure vessel steels and operating conditions. Static and cyclic loading, as well as concurrent microstructural changes such as temper embrittlement, will be included. The goal of this two-year project is to define the limits of materials and service parameters in order to ensure the safety and reliability of the eventual pressure vessels. *Program Manager: Roger Richman*

R&D Status Report
ENERGY SYSTEMS, ENVIRONMENT, AND CONSERVATION DIVISION

René Malès, Director

ASSESSMENT OF SUPPLY FROM NEW TECHNOLOGIES

This subprogram's objectives are the analysis and comparison of new technologies for the production and conversion of energy forms. It encompasses projections of costs and performance characteristics, dates of introduction, and relative contributions (through time) to the total energy supply. Unlike conventional supply analysis, which depends largely on historical data, this subprogram concerns technological developments that in most cases have no histories. Therefore, part of the research of the subprogram is directed toward the development of suitable analytic techniques. Normalization of methods of assessment across multiple technologies is a specific, ultimate objective.

In those technological areas where other EPRI divisions are supporting hardware development, close coordination is maintained to form a base for ESEC division analyses. These analyses will build on and also go beyond engineering-economic studies of new technologies. In particular, ESEC studies of new technologies will look at industry economics rather than individual plant economics.

The results of research projects in this subprogram will be used in making division supply projections. They are also expected to be of use in EPRI R&D planning and, more generally, in dealing with public questions on why various technologies are not immediately available.

The subprogram's areas of interest are far-ranging. It is helpful to categorize them as follows:

Category 1 New technology for producing conventional electric utility fuels (e.g., improved extraction of uranium)

Category 2 Production techniques for unconventional electric utility fuels (e.g., low-Btu gas, methanol, geothermal)

Category 3 New technology for producing energy forms competing with or otherwise impacting on electricity production (e.g., solar heating and cooling)

Category 4 New techniques for electricity production or storage (e.g., combined cycles, fuel cells, storage batteries)

Category 5 Development of analytic methods

In Category 1, a three-month study was completed in 1975 by Dr. Robert Anderson of Stanford University, a consultant to the subprogram, on the economics of physical beneficiation (upgrading) of low-grade uranium ores. Although uranium ores have not generally been successfully beneficiated up to now, in the future, as lower grades of ore are exploited, beneficiation could become economically attractive. This study identified potential reductions of 80% in milling costs through beneficiation as ore grades were lowered an order of magnitude below current mining experience. Additional studies to define the practical implications of this work are planned.

In the same category, contracts RP803-1 and RP803-3 have recently been initiated with NUS Corp. and S. M. Stoller Corp. to evaluate the economics of uranium extraction by the emerging technology of solution mining. In-house research into the potential for unconventional sources of uranium supply was conducted as a part of the research effort supporting the Energy Supply Program publication "Uranium Resources to Meet Long-Term Uranium Requirements" (SR-5, November 1974).

In Category 2, a study of geothermal energy is planned in the area of physical-economic modeling of alternative investment and production strategies. It is hoped that the project will begin late in 1976.

In Category 3, no projects are underway, but research is planned for a study of enhanced oil and gas recovery estimating techniques and for a study of the supply aspects of the solar heating and cooling equipment industry.

In Category 4, a research project will be initiated later this year to define the expected supply response of the metals and battery industries if there is a rapid growth in the demand for peaking and load-leveling batteries. Since this new technology is sensitive to the availability and cost of materials, the project goal is to identify potential material and manufacturing bottlenecks and critical lead times at an early stage of battery development. This is a new area of work under this subprogram. It is designed to complement simultaneous hardware development and is considered a prototype analytic framework that may eventually have application to other technologies.

In Category 5, but also overlapping Category 4 interests, a research project starting later this year will provide EPRI with a critical analysis of methods for estimating market penetration of new technologies into the electric utility industry (RP872). Two other projects in this category are already underway. One is RP663, in which the Denver Research Institute is conducting an identification and critical assessment of methods for characterizing the state of development of energy technologies. The other is a technology planning study (TPS 76-628) with Battelle, Columbus Laboratories, in which the track records and the strengths and weaknesses of various technological forecasting methodologies are being reviewed to determine which, if any, are applicable to the types of problems faced by EPRI.

Although the techniques described in the preceding paragraph are envisioned as possible tools to aid in supply forecasting, they may also have some relevance for EPRI-wide R&D planning.

Also in Category 5, a one-year project in which researchers are to develop improved methodologies for preliminary (i.e., preengineering development) economic screening of novel technological processes is to begin in September. Extensive additional work to develop consistent methods for across-technology assessments of processes in the engineering development stage will also be added to the subprogram. *Project Manager: Richard J. Urbanek*

ENERGY DEMAND AND CONSERVATION PROGRAM

Residential Sector

Work on energy use and conservation in the residential sector has continued to proceed along two fundamental paths: (1) assessing the technical performance of equipment and measurement of its energy use and (2) energy demand analysis. Research in technical performance and measurement is aimed at developing information on how specific energy-using residential equipment performs and on how and when it is used. These data then become part of the input into research on energy demand analysis. In this research the primary focus is on understanding residential energy-using behavior and applying that understanding to forecasting long-term residential energy use. In the April issue, James W. Boyd discussed residential energy demand analysis. The area of technical performance and measurement is emphasized in this report.

A study in progress since 1973 on fuel utilization in residential heating and cooling (RP137) is the keystone to our work on residential heating and cooling. Our objective is to develop the best information possible on the performance of major heating system alternatives, including electric resistance, electric air-to-air heat pumps, and gas furnace systems. In this project, researchers at Ohio State University (OSU) have already developed detailed information on the characteristics of buildings and households. To do this, they first placed extensive, comprehensive monitoring instrumentation on six single-family, detached houses and two apartments in the Columbus, Ohio, area. The dwellings were instrumented to capture information on the energy used by furnaces, on heat gain and heat loss through infiltration, on the heating loads carried by other appliances, on how often doors and windows were opened and closed, and on other variables of potential importance. Detailed data, collected at 15-minute intervals, were compiled and correlated with weather station information on such conditions as the intensity of direct and indirect solar radiation. This data file served as the basis for a detailed simulation model of fuel utilization in heating and cooling. After this model has been generalized and simplified, it is to be validated on information from a sample of single-family detached houses across the country.

The study is progressing in two phases. The first (to be completed in August 1976) is the development of the simulation model based on the collection and analysis of data from the Columbus sites. The second entails validating the simplified model on data collected from the remote sites. Throughout both phases, technical advice has been provided by a steering committee of representatives of the utility industry. Prepublication reviews of the Phase 1 reports are to be prepared by consultants.

In order to accomplish the objectives of Phase 2, eight residences are being metered for approximately one year in each of six utility service areas selected to represent a spread of degree days across the United States. In each area, a weather station is collecting data on temperatures and on the intensity of direct and indirect solar radiation. At present, data are being sent to the OSU researchers from these remote sites. These data will be used to test the model's accuracy for a range of climatic conditions and building construction practices. The final report on this phase of the project is expected to be completed in the first half of 1977.

In another study (RP432), researchers are determining the load and use characteristics of late-model residential heat pumps in actual operation. This project, being performed by the Westinghouse Corp. and jointly sponsored by the Association of Edison Illuminating Companies, is aimed at developing data on homes with such heat pumps. The instrumentation and measurement employed in this research are consistent with the data being developed for the OSU study of residential heating and cooling, discussed above. The load data are expected to be particularly useful for further projects aimed at determining the impact of residential heat pumps on utility system loads.

In addition to developing the basic data, Westinghouse is also running simulations of heat pump performance, using its own proprietary computer programs. These data are expected to be of considerable interest to the utility industry for energy conservation and marketing programs and for system planning. It is planned that the heat pump data will be input to the simulation programs being developed in RP137. Data are being collected from between 8 and 11 houses in each of 12 utility service areas—a total of 120 houses in a range of climates from Florida to Minnesota. Each area has its own weather station identical to those in the OSU research. Thus, between these two projects (RP137 and RP432), a set of data on direct and indirect solar radiation in 19 areas is being developed and is expected to be of value in other heating and cooling studies.

A third project in the area of technical performance and measurement involves a survey of monthly consumption of electricity by major household appliances (RP576). This project, begun by the Midwest Research Institute in 1975, is sponsored jointly with the Federal Energy Administration. Its objective is to provide representative data on the use of household appliances in correlation with data on the socioeconomic characteristics of the residents. Data are collected from a primary sample of 2000 households, 150 of which are metered for appliance use. They are expected to be an important source of information on socioeconomic factors and appliance usage that is comparable across regions. This information is expected to be a valuable input in conducting future household-level studies of energy-using behavior. *Program Manager: Robert Thomas Crow*

ENVIRONMENTAL STUDIES

An energy system consists of activities and technologies that transform raw energy resources into energy, satisfying final demand. Energy systems are dynamic and constantly changing: obsolete technologies are displaced by more efficient ones; other technologies are added to transform new energy resources into useful energy as traditional resources are depleted; existing technologies are modified to make them more useful or acceptable—in terms, for example, of their environmental impacts. In the production of energy, land is consumed; air and water quality are altered; human, animal, and plant populations are affected. These secondary consequences of energy production greatly complicate decisions involving the selection of technologies.

Within the Systems Integration and Model Analysis Program, studies are in progress to develop a framework for taking account of the environmental impacts as well as the other costs and benefits associated with alternative energy systems. The program interacts with the Environmental Assessment Department and with other groups in EPRI to develop an integration of the basic data they collect and the results of their analyses.

Several projects are underway. Brookhaven National Laboratory (BNL) is building a set of national and regional energy models (RP442). These models are to characterize energy systems in terms of existing technologies and energy resources (from supply through end use). New technologies and resources can then be introduced into the models in order to assess their potential usefulness. (The June issue of the *JOURNAL* contains a more detailed description of this project.) The BNL models are expressed as linear programming problems (i.e., minimizing a linear objective function, subject to a set of linear constraints). The objective function in the BNL models is total cost, and the constraints are final demand, resource, and environmental effects. The solution to the problem is an energy system operating at a certain level of activity. For a given solution, an inventory of residuals can be derived. For example, if coal-fired generating plants are in the solution, then estimates of CO, NO_x, SO_x, particulates, water wastes, and so forth can be calculated on an annual basis.

In order to obtain finer detail in the electric utility sector, a production simulation model of a regional electric utility is being developed in Schenectady, New York, by General Electric Co. (RP208). This model will be used in the Sulfate Regional Experiment (SURE) project (RP862), under EPRI's Environmental Assessment Department, as a logic for assembling load and emission data for the years between 1980 and 1990. In addition, selected simulations may be made during this period to provide hour-by-hour input on emissions into the atmosphere-dispersion model being used in the SURE study.

To better understand and model the relationship between emission inventories (atmospheric) and the environment, Battelle, Pacific Northwest Laboratories (RP805), is characterizing receptors (plants, materials) in terms of emissions (type, concentration, time of action) and is reviewing the types of models (under this characterization) that might be used to translate emission inventories into their environmental impacts.

Also in progress is a one-year project ending in August, sponsored jointly with the Solar Energy Program of the Fossil Fuel and Advanced Systems Division, to develop methodologies for assessing the environmental impact of large-scale solar power stations (RP552). *Project Manager: J. Karaganis.*

THREE—DIMENSIONAL MONITORING: DIFFERENTIAL ABSORPTION LASER RADAR

Lasers used to be spoken of as an answer in search of a question. One question they will soon be used to answer is, "How much pollution is out there?" The biggest advantage of remote measurement by laser is that the investigator does not have to go "out there" to make the measurement. Differential absorption laser radar can be used to measure air pollution several kilometers away, with a sensitivity in the parts-per-billion range.

In practice, this means that researchers can obtain real-time, three-dimensional chemical concentration data on plumes without flying through the plumes in an aircraft. Or, in

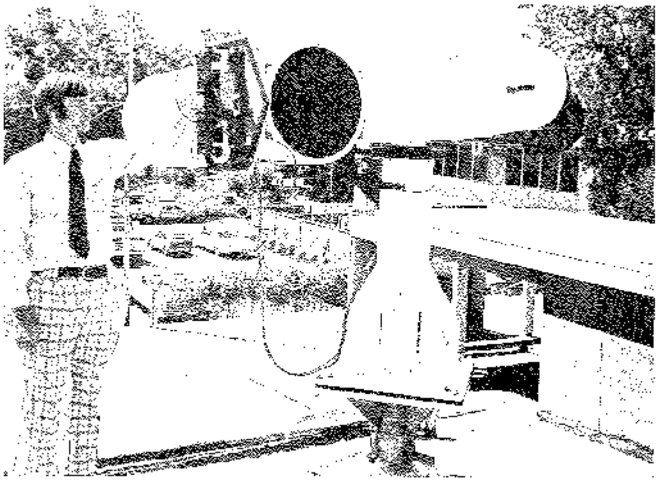


Figure 1 The 16-in, f-3 telescope receiver, specially designed for measuring air pollution, costs substantially less than comparable astronomical systems.

Figure 2 The high-energy, tunable infrared laser is the core of the remote measurement system. The current spread-out construction allows easy modification, but the final version will be substantially more compact. Here with the laser (from left): Harvey Melfi, EPA; Robert L. Byer, Stanford University; Alexander Stankunas, EPRI; Michael MacCracken, ERDA; and Glen Gordon, NSF.

more routine operations, ambient monitoring of the atmosphere around a power plant site can be done from one location, instead of requiring a spread-out network of expensive and maintenance-intensive point monitors.

EPRI is sponsoring work to determine the applications and limits of remote measurements, using a high-powered, tunable infrared laser as a source and a telescope system as a receiver (RP486). Dr. Robert L. Byer of Stanford University is measuring gases in the atmosphere with such a system. His work will help define which wavelengths to use in measuring specific compounds, and perhaps even more important, it is expected to show whether there are any as yet unforeseen problems to solve before a system suitable for field use can be built.

In the past year Dr. Byer has completed construction of the optical system and computer hardware needed to analyze the signals and is beginning to make outdoor measurements. His program includes the measurement of concentrations of SO_2, NO, NO_2, and CO, as well as air temperature profiles, wind velocity, wind direction, and relative humidity at various altitudes.

The principle by which differential absorption laser radar operates is simple, although the equipment requires application of the latest technology. A short pulse of light at a certain wavelength is emitted into the atmosphere. A portion of this beam will be reflected or scattered back toward the detector by dust and other particles all through the atmosphere. Light returned by particles closer to the source will arrive sooner than light returned from farther away, so light from any given distance can be identified by its time of arrival. If the wavelength of light sent out is absorbed by some gas in the atmosphere (such as SO_2), less will be returned than if the light is not absorbed.

Since, for a given path length, the amount of light absorbed is directly proportional to the concentration of the absorbing species, the amount of gas present in the region of interest can be calculated. The distance resolution depends on the length of the laser light pulse and the speed and sensitivity of the detector. With existing equipment, it is possible to measure gas concentrations in any 75-m segment along the beam path, out to 2 kms. For example, it is possible to measure the CO concentration between 300 and 375 m away and to distinguish it from CO at 375–450 m.

By sending out two pulses, one at an absorbed wavelength and one at a slightly different wavelength that is not absorbed, the light attenuation due to absorption by the gas in a given segment can be readily determined. The two-pulse method corrects for factors other than absorption that could cause the returned light to be of lower intensity than it should (such as intense localized scattering by dust clouds or atmospheric scintillation).

Many technological problems remain to be overcome before a practical system for environmental monitoring can be built. But, with input from research in several areas, the needed advances are being made at an accelerating rate. The high-powered, tunable infrared laser, for example, was originally developed for isotope separation, and the basic sensing system design is similar to that for particulate sensing (LIDAR). New lasers, faster signal processors, and improved detectors are constantly expanding the horizons for environmental monitoring. EPRI's goal is to help make this new technology available to solve some of the pressing problems of the power industry. *Project Manager: Alexander Stankunas*

Ruth Davis: Conservation Advice for Consumers

Ruth Davis of the National Bureau of Standards holds little hope for energy conservation by an American public largely unaware of the real nature of the energy problem.

□ An EPRI interview

Conservation of energy is being urged on many fronts. In April of this year the Ford Administration focused more sharply on energy conservation. In its budget request for fiscal 1977, ERDA asked Congress for $120 million to support conservation research, 63% more than had been requested earlier. This amounted to a major policy change, elevating energy conservation to where it ranks with development of new energy sources.

Environmentalists have been calling for energy conservation all along, some claiming that we can reduce growth of energy demand to about 2% a year. (Small as this seems, it doubles our annual energy use in 35 years; and a 3% annual growth does so in 24 years.) A recent EPRI handbook, *Efficient Electricity Use,* details conservation techniques that can be used to save electricity by everyone from the design engineer to the homemaker.

Ruth Davis, however, is "not at all confident" that the average American consumer has the knowledge or the will to conserve energy. In a survey of public attitudes toward the U.S. energy situation that she and colleague Shirley Radack conducted in 1975, Davis found the public lacked understanding of the nature and dimension of the energy problem. For instance, people generally equate energy with gasoline, but not with plastics, nylons, and synthetic shirts. Few people are aware that petroleum goes into making nylon carpets, plastic bags, synthetic fibers, vinyl bottles, detergents, and cosmetics. And the rising cost of food is rarely linked in the public mind with the increasing cost of energy.

A major obstacle to energy conservation, the survey showed, is the high value placed on the automobile. Americans spend more on their cars than on health care. Only food, shelter, and household operations outrank the automobile in amount spent on necessities. The convenience, reliability, comfort, and privacy of the automobile are strong attractions for Americans. And many of those polled said they would not use mass transit—an

"Only food, shelter, and household operations outrank the automobile in amount spent on necessities."

alternative to the private car—until the incidence of crime on public transit is reduced.

The survey also found that "no major spokesman for the consumer has emerged on energy problems." This fact, Davis notes, "reflects the multiplicity and complexity of energy problems. Energy touches many different issues—recession, inflation, taxes, environment, foreign relations; and many different groups have a stake in energy policies—automobile manufacturers, unions, oil companies, the transportation industry, environmentalists, consumers.

"Environmentalist groups, Ralph Nader's organization in particular, have assumed vigorous roles in opposition to projects they feel might damage the environment. They have been successful in delaying the construction of nuclear power plants. As public interest groups, they have advocated cheap energy for the consumer, yet have opposed projects that proposed to increase energy availability, such as the nuclear plants, off-shore drilling for oil, exploration for shale oil, and the like.

"The inability of Congress and the president to deal with the problem of imported oil—whether to tax or not, whether to restrict imports—demonstrates the lack of consensus in this country. Congress, representing specific and often conflicting regional interests, has been completely unable to assume a leadership role in energy policy," Davis observes.

The American public, it was found, places blame for energy problems on industry, the government, and the environmentalists. Many people suspect the oil companies of manipulating shortages in order to force prices up. And the automobile industry is charged with continuing to promote big, gas-guzzling cars.

"The trend over the last several years," the survey noted, "has been to manufacture heavier cars with optional features that require power and reduce mileage. The automobile companies, often in conjunction with the auto workers' unions, have tended to blame antipollution standards for the poor gasoline mileage of the newer model cars. There has been a resistance to radically change models because the automobile makers are uncertain of public opinion toward smaller cars."

"People generally equate energy to gasoline, but not to plastics, nylons, and synthetic shirts."

Architects and builders were blamed for the poor design of houses with little thought given to energy required to heat and cool them. "The availability of cheap energy in the past dictated interest in initial building costs rather than in life cycle costs," the survey noted. "The extensive use of glass in high-rise buildings has been cited as a particularly high energy waster."

It was evident that "the uncertain political climate of the past several years has bred distrust and suspicion, and general dissatisfaction with government. Specific charges leveled at the federal government include holding down oil prices and thereby reducing incentives to discover new sources, and enveloping industry in regulations which discourage capital investment and initiative."

It was further noted that environmentalists "have been singled out for criticism for delays that have occurred in developing nuclear power plants. The highly visible actions of the environmentalists tend to be blamed more by the utility companies than by the American public."

To Davis the survey indicates that "there isn't a sound basis for the public to use in making decisions on how much it is willing to conserve and how hard it is willing to try to conserve." It also shows that "there isn't any attempt being made to provide that sound basis by anybody with the public interest in mind." And it points out that existing environmentalist and conservationist groups "are not directly meeting the needs of the public in this regard."

Davis further observed that "the cynicism of the public about there really being an energy crisis—in view of all the other nonissues they've been forced to swallow in the last several years—was such that they were not sure they were doing the right thing by conserving. I think one of the major reasons that you don't see an honest effort to conserve is because so many people simply feel they are being taken again." She adds, "I have a strong belief that all of us would be willing to do a lot more if we felt that there was an honest need and that everyone was having to take the same steps to conserve."

Ruth Davis stresses that she is "a strong believer in protecting the environment," and that is why she is "very disturbed by the fact that the environmental movement gives the impression of just being negative." She would like to see a "strong environmental advocacy group with a strong environmental science base. We need to develop environmental science and technology as rapidly as we're moving ahead in energy technology," Davis stresses while noting, "we obviously aren't doing it."

She points out, "There's no environmental industry in this country so there's no lobby to push for environmental interests. Environmental concerns come from a very fragmented public and some honest, enlightened conservation groups. But there is no industry backing them as there is in energy." And for this reason, she says, "If one would try to set up an environmental EPRI, there'd be no source for the funds needed."

Davis would like to see Congress set up an environmental counterpart to ERDA, but doesn't hold out much hope. The federal thrust to protect the environment, as she sees it, was spent in establishing the Environmental Protection Agency.

"The concerns for focusing attention on environmental science and technology got dissipated when EPA was set up," Davis says. "Congress said, 'Thank heaven, we've done our job. Now it's up to the universities and the like.' But the universities can't train environmental scientists for whom there is no market, and industry hasn't shown any real desire to develop environmental science and technology."

EPRI's mission of funding and managing research and development in new electric energy technology emphasizes that the results are to be compatible with the environment. Of the $129 million projected in EPRI's 1976 research and development program plan, nearly $65 million has been budgeted for environmentally related projects.

"No major spokesman for the consumer has emerged on energy problems."

Davis feels that EPRI can make a significant contribution to conservation by developing better transmission and distribution systems that would give us "more cost-effective delivery of electric energy." An effective way to approach this task, she believes, is to apply systems and communications science in working out nationwide networks for transmission and distribution. From her work on the Advisory Council, however, Davis says she doesn't see much evidence yet of EPRI's use of the systems approach in designing such networks.

Davis commented that EPRI has achieved in its three years of existence "enough successes and advances in the right direction that it is looked to as a model for advancing a specialized kind of research and development." She says that EPRI's reports receive "considerable respect by the R&D community. I know that directly. I think EPRI is producing what probably is the best set of reports in the environmental area that have come from energy R&D of any kind."

Davis points out that she places EPRI reports on a special shelf in the Bureau of Standards library so that everyone there has access to them. "And they're much sought after," she comments.

As a specialist in computer and communications science, Davis is concerned that EPRI "does good modeling and that it gets adequate input—that EPRI, first of all, uses modeling and simulation to the extent possible, and second, uses the best techniques and has good validation of its modeling and simulation."

On the other hand, Davis has strong views on what EPRI should not do. She does not want to see EPRI "become an advocate of any industry position or a witness in support of any particular industry or utility position." Her experience at the Bureau of Standards has taught her that "you can't mix being a good research and development organization with being an advocate of a particular company or industry position."

Davis feels that the Advisory Council

"I feel the Advisory Council owes it to itself to stay free and loose and not become a set of bloc voters."

"has within it almost all the needed special interest capabilities and talents required to represent the public interest." However, she pointed out that no one on the Council represents the consumer and she feels this is an omission that ought to be corrected. Such a representative would attend to consumer interests as they are affected, for instance, by energy legislation and new utility rate structures.

Davis does not want to see the Council become "a collection of solidified special interest groups. I sincerely hope that it doesn't become that," she says. "I feel the Advisory Council owes it to itself to stay free and loose and not become a set of bloc voters."

As for the working agreements between EPRI and various federal agencies for cooperative efforts in energy research and development, Davis believes that "Chauncey Starr has been a sheer genius in the way he's effected these agreements." And although she admits that "it's too soon to judge [the effectiveness of the agreements], certainly it all bodes well. The agreements were a necessary condition for success."

A memorandum of understanding with her own agency is in effect, establishing basic guidelines under which measurement technology information on electric power equipment and systems can be shared. EPRI also has cooperative agreements with ERDA, EPA, and NASA for joint funding and conducting a wide range of research projects.

What prompted Ruth Davis, whose busy professional life would strain the energy capacity of a 1000-megawatt power plant, to agree to serve on EPRI's Advisory Council?

"An underlying thread through my entire career," she explains, "has been an interest in seeing the best way in which new fields of science and technology can be applied, particularly those fields that interact most directly with people. I find the new breed of energy science and technology, as it interacts with individuals and the environment, to have enormous merit and worth my while to participate in it."

She adds, "I think EPRI is in the vanguard of advancing science and technology in cooperation with government, industry, and special interests."

Ruth M. Davis has shaped a *summa cum laude* career. Since receiving BA, MA, and PhD degrees summa cum laude (the last in 1955 in applied mathematics and physics at the University of Maryland), she has turned her brilliance to government service, earning numerous honors and commendations over the past 20 years. In 1973 Dr. Davis was presented with the Rockefeller Public Service Award for Professional Accomplishment and Leadership and a tax-free $10,000 grant, the most prestigious annual award given to federal career employees.

As director of the Institute for Computer Sciences and Technology at the National Bureau of Standards, Ruth Davis holds one of five top management posts at the NBS, with a budget of some $6 million and a staff of over 150.

Before taking up her current position at the National Bureau of Standards in 1970, Dr. Davis was director of the Lister Hill National Center for Biomedical Communications. She has been a consultant to the government of the Republic of China, assisting in planning and setting up a governmentwide electronic data processing structure and facility. She has lectured or taught at American University, Harvard University, the University of Pittsburgh, and at universities in Finland, Norway, and Sweden.

Since 1962 Dr. Davis has done notable work in such fields as automation, robotry and control systems, automated information management, biomedical applications of computers and communications, computer networks, and applications of computers and communications in intelligence and reconnaissance operations.

Early in her professional career, as a research mathematician with the navy's Applied Mathematics Laboratory, David Taylor Model Basin, she and a colleague developed the first programmed set of techniques for the design of nuclear reactors, subsequently used widely in government and industry for the design of submarine and shipboard reactors. Other original work includes the first analyses and designs of military command and control systems, and techniques for the design and use of automated display-centered information systems.

In addition to the 1973 Rockefeller award, Ruth Davis received the federal Woman of the Year Award and the Gold Medal Award of the Department of Commerce in 1972, and numerous commendations from the U.S. Navy for her work over the years. She is a member of several professional societies and academies, various councils and boards, and has published extensively.

In July Dr. Davis succeeded Arthur C. Stern as chairperson of EPRI's Advisory Council.

EPRI and ERDA Sign R&D Agreement

EPRI has enjoyed a productive working relationship with the Energy Research and Development Administration (ERDA) since ERDA's founding in January 1975. Now a Memorandum of Understanding formalizes that relationship and prepares for even broader coordination and cooperation in energy technology development.

On November 27, 1973, Dr. Chauncey Starr, president of EPRI, gave testimony before the House Committee on Government Operations on the proposed formation of the Energy Research and Development Administration (ERDA). Concluding his remarks, Dr. Starr made the following statement:

"We look forward to the opportunity of working in partnership with the proposed federal agency. There is a balanced set of roles which an agency such as ERDA can fulfill in the national interest and which EPRI will complement in helping the electric utility industry deliver energy to the consumer. The energy research needs of our nation are so vast and so important that I can only look forward with enthusiasm to the enhanced efforts which would be represented by the proposed agency."

Fourteen months later (January 1975), ERDA became a reality, coordinating federal energy research by bringing together the energy-related programs formerly administered by the Department of the Interior, the National Science Foundation, the Atomic Energy Commission, and the Environmental Protection Agency.

EPRI and ERDA share numerous areas of mutual interest and closely related concerns in the efficient and economic marshalling of this nation's research, development, and demonstration resources toward meeting future electric energy demands for the overall public good.

The two organizations are cooperating on 31 energy research projects with a combined funding value of approximately $84 million. Contemplated EPRI–ERDA projects would bring this figure to over $200 million.

To formalize this productive working relationship, Dr. Robert C. Seamans, administrator of ERDA, and Dr. Starr recently signed a Memorandum of Understanding that provides for broad energy R&D cooperation between the two organizations.

Program coordination

The purpose of the agreement is to encourage a coordinated program for development of improved technology "to advance the safety, reliability, efficiency, and environmental compatibility of the production, transmission, distribution, conservation, and utilization of electric energy." It sets forth basic guidelines under which the two organizations will work together in a complementary manner to avoid duplication of effort and to pool administrative, technological, and financial resources.

This agreement succeeds an EPRI-Atomic Energy Commission (AEC) memorandum signed in October 1974, under which EPRI and ERDA have been operating.

"We cannot overemphasize the importance of this agreement as a milestone in coordination between major sectors of society in their attack against the nation's energy problems," Dr. Starr said. "Close R&D cooperation between ERDA and EPRI will maximize efficiency in developing better energy technology. At the same time, it should encourage greater cooperation among all energy-related industries in meeting future energy requirements."

Breeder project

The largest EPRI–ERDA project now under management is a $30 million, 30-month program to develop design concepts for a commercial liquid metal fast breeder reactor. The ultimate goal of this program is to hasten commercialization of the breeder reactor, which generates 50 to 100 times as much power from the same amount of uranium as the conventional light water reactor. Under the program, three competitive design teams, each composed of a reactor vendor and an architect-engineering firm, are developing firm designs, cost estimates, and construction schedules for a prototype of a large-scale power plant.

The feasibility phase of a multimillion dollar project, cofunded by EPRI and ERDA, to develop a utility-oriented test facility for large-scale battery systems, has been successfully completed. The Battery Energy Storage Test (BEST) Facility Program is now in the preliminary engineering phase.

Such battery systems could one day play a key role in leveling electric power loads for utilities. This would reduce the requirement for costly generating facilities that are needed only during peak power periods.

EPRI, ERDA, and General Cable Corp. are cooperatively funding a research study to determine ac conductor and pipe loss on pipe-type cable systems in electric power transmission.

Other EPRI–ERDA projects relate to fusion, solar energy, environmental protection, energy supply and demand, nuclear safety and engineering, electricity transmission and distribution, and magneto-hydrodynamics.

Information exchange

Of comparable importance to their cooperation on specific research projects is the open information exchange between EPRI and ERDA. This has already resulted in cost- and time-saving program coordination. It is also factoring utility industry experience, needs, and priorities into the nation's overall energy research and development program. And it is helping to focus a large and highly qualified assemblage of energy research specialists on a coordinated program of energy technology development.

Cooperation under the Memorandum of Understanding encompasses the following activities:

- Information exchange in agreed-on areas
- Work for EPRI in ERDA facilities
- Work for ERDA in EPRI facilities
- EPRI–ERDA joint funding of work by third parties
- Coordinated parallel or sequential contracting by ERDA and EPRI for related work by third parties
- Such other activities, including stationing of personnel, as may be decided from time to time

Implementing the agreement

EPRI and ERDA will provide for senior management overview of the cooperative activities undertaken. "To this end, the president of EPRI and administrator of ERDA, or their designees, will meet at least annually to exchange information concerning long-range programs, specific programs for the next fiscal year, status and/or results of all significant interactions, general progress and problems, and a summary of long-range and short-range programs of mutual interest."

Operation groups will be established for each discrete area, or group of areas, of common technical interest to achieve parity of representation throughout the breadth of the relationship. The operation groups will designate project groups for the technical monitoring of jointly funded contracts.

Throughout the life of the agreement, "the parties will use their best efforts to assure that there is a maximum productive formal and informal exchange of information on the plans, ongoing efforts, and results of research work in the agreed-on areas of cooperation, within appropriate discretionary limitations."

World Energy Leaders Meet

The focus of R&D planning on energy needs was the topic discussed at an international symposium in Washington, D.C. Shortages are growing more severe everywhere—except in the U.K., where North Sea oil supplies relieve the crisis.

It may surprise no one to learn that the United States is a great deal further from having a national energy policy than are Great Britain, France, Sweden, and Japan.

This emerged as a significant—if unintended—result of an international symposium sponsored by EPRI in Washington, D.C., on May 5. The broad-scale, high-level survey of energy R&D planning was attended by 250 energy officials and research leaders from five continents.

This is not to say that each country that shared the agenda with the U.S. is committed to a specific course of action. But as energy research leaders described the current status of R&D planning for electric power supply in these four industrial nations, it was clear that each is moving purposefully to meet its needs.

France, for example, decided several years ago to cease building fossil-fired generating plants and to depend entirely on nuclear power for future capacity additions or replacements.

Britain is in the fortunate position of expecting self-sufficiency if not a surplus of energy for a 10–30-year period after 1980, thanks to its North Sea oil supplies. Consequently, Britain is concentrating its R&D on the period thereafter and is focusing its major R&D effort on conservation, nuclear, and coal.

Japan, aware of serious deficits in energy sources in the near future, is planning to diversify its power supply as its electricity demand doubles between 1974 and 1985. There the R&D focus is on building a structure for stable energy supply in the period beginning the latter half of the 1980s.

Beginning in 1950, Sweden held nationwide debates on various aspects of energy and now has an energy policy tied to such social goals as full employment, economic equality, better welfare, and security. This policy is based on decelerating the growth of energy consumption, active procurement of oil, and ensuring the supply of electric power.

In contrast, while both the U.S. government and private industry have hammered out programs that are cogent efforts to cope with the realities of a serious (even menacing) situation, these programs are not yet matched by national agreement on what the U.S. goal should be, much less on how to proceed. And there is wide disagreement outside the energy R&D community—in government and among the public—on the proper role of nuclear and of the breeder; what can be expected (and when) of solar energy, fusion, liquefied natural gas and coal liquefaction, geothermal, conservation, and the more exotic sources (wind, wave, tidal, ocean temperature gradient, biomass). There is even disagreement on whether coming generations will need more energy.

This was not stated in so many words by either Dr. Robert Seamans, administrator of ERDA, or Dr. Chauncey Starr, president of EPRI—both of whom made positive statements about the programs and the approaches of the organizations they head. But the lack of a firm policy structure for energy development in the U.S. rang out between the lines. It was equally implicit in the words of John Winger, vice president and head of the energy economics division of the Chase Manhattan Bank, a member of the National Petroleum Council and of EPRI's Advisory Council.

Winger drew laughter with his comment: "Based upon what has happened in the past and what is happening right up to the moment, we can expect Europe and Japan to be getting signatures on the dotted line for delivery of external sources of energy while we are still holding hearings." And he concluded his luncheon talk by saying, "In the future, we're going to have to allocate a larger proportion of our natural resources to the development of an adequate supply of energy. We must pay the price. If we're unwilling to pay that price, I think we're going to have to pay a greater price in terms of the unemployment and economic problems that we will otherwise inherit."

Winger supported his statements with charts showing that energy use and GNP are closely linked and that if massive unemployment is to be avoided, there must be further economic growth and sufficient energy to support that growth. He presented statistics showing these relationships to be valid for the U.S., for Western Europe, and for Japan.

Refuting the charge that the U.S. is grossly wasteful of energy because it has only 6% of the world's population but uses 30% of its energy, Winger emphasized that the U.S. accounts for 30% of the world's GNP. Rather than reasoning that the U.S. is wasteful of energy, we should

reason that the U.S. is more efficient in the utilization of people because the extensive use of energy-powered equipment has enabled its people to be more productive. He also observed that many who rely heavily on extensive energy conservation through further gains in efficiency overlook the vast gains already achieved. "While there is no doubt in my mind that we will find ways and means of saving energy, we must be realistic and recognize that the scope of further gains is not nearly as great as some might suspect," he said. "And we must also recognize that technological progress will continue to bring into existence new uses for energy."

Top, l to r: Naohei Yamada, Japanese Central Research Institute of Electric Power Industry; Michel Pecqueur, French Atomic Energy Commission. Center: Chauncey Starr, EPRI; John Winger, Chase Manhattan Bank; Gunnar Hambraeus, Royal Swedish Academy of Engineering Sciences. Bottom: Wolf Häfele, Institute for Applied Systems Analysis, Austria; Robert Seamans, ERDA; Shearon Harris, Carolina Power & Light Co. and EPRI.

The outlook at EPRI

Many solutions have been proposed to the energy issues facing the U.S. and other countries, according to Chauncey Starr. "I believe that even though we may develop every conceivable method of improving our energy use and of supplementing our energy resources, we will barely be able to meet the foreseeable demands for the coming decades. The national consequences of energy malnutrition are very serious, and the avoidance of these societal penalties, we believe, ought to be a national objective.

"At EPRI, we have adopted several basic premises that may be questionable or debatable on philosophic grounds, but from the point of view of our planning, we do not question them," he went on.

In any event, the task confronting electric supply planners is a stupendous one, Starr affirmed. He then commented that the direct relationship between energy input and employment (which Winger charted for the last 20 years) has been as firm since 1890 as it has been in the last 20 years. The labor force can thus be projected to the year 2000 because almost all its membership is alive now: even if there is zero population growth from here on, the size of the labor force will not be changed by more than a few percent.

From the almost dramatically tight relationship between energy use and employment, it can be seen that the energy input required in 2000 will be about $2\frac{1}{4}$ times the total energy consumption in the U.S. today—"obviously a scary number," Starr said.

Relating the total energy requirements to the probable electricity portion, the planning target for the year 2000 can be projected as 7500–10,700 billion kilowatt hours, or 3.8–5.3 times present levels. "In other words," he continued, "if no one does anything and business as usual goes on, we may have to produce five times as much electricity as we're now producing. And if we put in all the reasonable conservation factors that we know about, we may end up having to produce four times as much energy, and this isn't much of a range. Whether we're going to need three, four, or five times as much electricity in the year 2000 as we're producing today, we've got to start that same mountain climb, regardless of where the top is going to be."

To study where the increase might best come from, EPRI has looked at almost every source of electricity generation. "The studies indicate that even if we push in all these directions, coal and nuclear or a mix of those two represent 86% of what we have to count on for generation, and there's just no way to get around that problem," Starr said.

In the near term (defined as commercialization within 10 years), the biggest problem and our primary resource issue is how to use high-sulfur, high-ash coal.

For the mid-term (10–25 years), the focus of EPRI's efforts is on liquefaction and gasification. "We're saying to anybody who wants to look at the numbers that no matter how fast we push coal gasification and coal liquefaction, it will just begin to make a real input to utility operating systems near the year 2000."

In the nuclear area in the mid-term, EPRI is concentrating on closing the fuel cycle and on the fast breeder. Improving reliability and availability and lowering capital cost are other major programs. For the long term (beyond 25 years), EPRI is looking at fusion and solar.

EPRI is also working in the areas of energy storage; generic technical problems, such as materials corrosion; transmission and distribution; conservation and environmental control. "Roughly half our work is devoted to solving the problems raised by environmental considerations," Starr said. "Probably the one thing that irritates us most in our public communication is the accusation that the industry, the technical people in it, are not concerned with environmental matters."

ERDA's view

Robert Seamans, like Starr, began with some sobering statistics. But where Starr showed the magnitude of the task before us, Seamans showed how unfavorable a position we are starting from. The U.S. hit its peak petroleum production in 1970 (about 10 million barrels a day) and production has been declining since. "In mid-March of this year, for the first time in our history we actually imported more oil than we produced domestically," Seamans said, noting the truly catastrophic implications of such dependence on our national security, our international political independence, and our future economy. Furthermore, natural gas production hit its peak in 1973 and has been declining since.

ERDA is projecting reduction of energy consumption through conservation by as much as 25% by the year 2000.

"A most difficult problem for ERDA planners is the timing element: how fast or how soon we need certain changes and how fast or how soon we can achieve certain objectives. This is difficult," Seamans explained, "since scientific or technological breakthroughs can be neither predicted nor scheduled, and we are unable in many cases to alter the pace at which we proceed by throwing more money or manpower at the problem." He noted that this is a particularly difficult concept for much of the lay public to understand.

For example, it will take "a good many years—well past the mid-1980s—to bring the cost of photovoltaic energy conversion down from the present $20,000 per peak kilowatt to the $200 per peak kilowatt required for commercial impact," Seamans said. Similarly, fusion "is a technology for the next century," and no major impact is expected from the breeder "much before the mid-1990s."

ERDA's highest priorities, Seamans said, are (1) conservation; (2) expanding the application of enhanced oil and gas recovery techniques; (3) expediting direct utilization of coal; (4) developing the basis for a synthetic liquid and gas fuels industry from coal, oil shale, and biomass; and (5) establishing a complete LWR fuel cycle in the private sector.

The situation in Great Britain

Because of the expected period of self-sufficiency mentioned earlier, one of Britain's serious problems is the danger of complacency, according to Dr. Walter Marshall, deputy chairman, U.K. Atomic Energy Authority. Another problem, which most other industrialized countries won't have the luxury of having to cope with, is whether to export surplus oil to earn income or to leave it in the ground and stretch its availability for domestic consumption.

"The crossover point when energy shortage again becomes a harsh reality is a subject of considerable debate," Marshall said. "Pessimists assume that it will be about 1990; optimists hold it will not come until about 2010; but there is no consensus because we genuinely don't know how much oil and gas there is on the continental shelf."

In the meantime, Britain is studying the use of wave power, tidal power, wind power, solar power, and geothermal power. Of all these, Marshall sees wave power as the most promising, and Britain has launched "what for us is a very sizable research program" to develop electric generation by wave power.

"We are not terribly enthusiastic about tidal or wind or geothermal power," Marshall said. "The prospects of solar power in the U.K., however, do not seem negligible. That's hard to reconcile with the well-known characteristics of our climate, but it does seem to be promising."

Marshall commented that the principal conclusion of the most recent overall strategy study is that "we can see no acceptable future for the U.K. without simultaneous work on coal utilization, energy conservation, and nuclear power. Without any of those three, it is very difficult indeed to see the U.K. being a comfortable place to live."

Plans in France

The Commissariat à l'Energie Atomique and the national utility, Electricité de France, were represented on the program by Deputy Administrator General Michel Pecqueur and Director of Research Maurice Magnien, respectively.

France is projecting "a relatively high rate of economic growth" (between 5% and 6% for GNP until 1985) and is hoping for a reduction of about 15% in total energy consumption over the 1975–1985 decade by eliminating energy waste, using existing energy-saving techniques, and developing and applying new ones, according to Pecqueur.

In 1973 electricity represented 22% of total energy consumption, and by 1985 it is hoped this will be increased to 36%. Of the 1985 generation, 70% will be by nuclear plants—meaning that all baseload electricity will be nuclear-produced. This would permit a reduction in dependence on imported sources of energy from today's level of 75% to 60% by 1985.

It is not considered likely that new energy sources will greatly modify the supply forecast for 1985. Maximum impact of R&D will be on energy-saving techniques: influencing consumer conservation or modifying industrial production processes; developing a method of offshore oil research in deep ocean water; utilization of energy sources "which can be used rapidly," such as geothermal or waste heat; devising a means to stabilize the proportion of electricity in the total energy balance; and fully developing nuclear power, including fuel cycle, waste disposal, and the like. Coal gasification and liquefaction have little interest for France because of its very limited coal resources.

The use of hydrogen (obtained from water by electrolysis or nuclear heat) as fuel is "deemed worthy of consideration, but cautiously, because of the uncertainties," Pecqueur said. Solar energy work is still in the preliminary phase.

However, as is already fairly well known, France is placing considerable effort and emphasis on the LMFBR, and Pecqueur announced that the French government has just given the green light for construction of the 1200-MWe Superphénix, a scale-up of the highly successful 250-MWe Phénix. Superphénix will be built in France as a collaborative effort of the French, Italian, and German utility industries.

Speaking for EdF, Magnien described the nuclear program buildup that resulted in the award last year of perhaps the largest contract ever let in the electric industry: sixteen 925-MWe nuclear plants, at a cost of $1.5 billion. Capital cost of these plants is $430 per installed kilowatt. Operating cost in France's nuclear plants today is 15 mills per kilowatt hour as compared with 27 mills in oil-fired plants, Magnien commented.

Decisions in Sweden

Professor Gunnar Hambraeus, director of the Royal Swedish Academy of Engineering Science, gave an account of the long and bitter energy debates in his country over conservation, zero energy growth, and nuclear power, as well as other issues, and the decisions reached by the government a little more than a year ago.

Total energy had been growing about 4.5% per year in recent decades; it is to be decelerated to about 2% per year until 1985, with an eventual goal of zero growth—despite a population growth that is presently 0.5% per year.

Electricity is in higher demand than other forms of energy and its annual growth rate of 7% will not be reduced by more than 1% (to 6%) by 1985.

Sweden has no domestic oil and aims to reduce its dependence on imports, trying to increase the use of coal, coke, and liquids from paper, pulp, and wood. Hydro's contribution to total energy will decrease from its present 14%, and nuclear's will increase from 0% to 12%.

The government will support oil prospecting both domestically and abroad, and a state oil company will be set up.

New policy in Japan

On December 19, 1975, Japan adopted a formal general energy policy to establish a stable, long-term supply of energy for the nation. Japan is trying to solve the problems inherent in being one of the foremost energy-consuming countries in the world while being dependent on foreign imports for nearly 90% of its energy.

This policy establishes two large-scale projects: the Sunshine Project and the National Research and Development Program.

The Sunshine Project covers research in solar energy, geothermal energy, coal gasification and liquefaction, and hydrogen energy. Not only will this project draw on all sources of expertise within the country, including industry and universities, but other countries may be invited to cooperate as well. (It was budgeted for $8.296 million in 1974 and $13.260 million in 1975.)

The National Research and Development Program, aimed at "promoting systematic and efficient projects on new technologies for exploitation of natural resources, preservation of the environment, and enhancing the living standards and public welfare of the people," is composed of 11 projects, including one on MHD power generation.

In addition, the electric power industry has its own long-term technology development program, which this year is focused on five areas: nuclear power, environmental protection, bulk power transmission, new energy sources, and energy conservation. There are 29 research projects in these five categories.

Analyzing the worldwide problem

Supporting the regional and national presentations by other speakers, a truly global picture of medium- and long-range aspects of energy systems was developed by Dr. Wolf Häfele, former director of the Karlsruhe Reactor Research Institute and now deputy director of the International Institute for Applied Systems Analysis, Schloss Laxenburg, Austria.

The cheap energy systems based on oil and gas and characterized by low capital costs and the possibility of relatively easy transportation have suddenly become the systems of yesterday, and to take their place, the world is struggling to settle on the best transitional substitutes, but these will be more expensive. "For tomorrow," Häfele said, "we will have abundant amounts of cheap fuel, but this refers to the operating costs and the fuel costs; the capital costs for all future options for large-scale energy supply will be significantly higher." He predicted that nuclear and a new coal technology will be basic and "solar will probably play a significant role." There will also be large-scale transportation and storage of "secondary forms of energy," such as liquid air, liquid hydrogen, or ammonia.

"We must continue with the fast breeder because it is the first example of a facility for an unlimited supply of energy, and so far, it is the only one that is operationally available," he said. He also foresees in situ liquefaction or gasification of coal; energy conservation; production of hydrogen, "preferably by biosolar power"; and "of course, fusion."

At the Institute

NEW ADVISORY COUNCIL OFFICERS


Davis


Netschert


Bloom


Lieberman

EPRI's Advisory Council met in Palo Alto May 27 and 28 and elected new officers for 1976–1977.

Ruth M. Davis, director of the Institute for Computer Sciences and Technology of the National Bureau of Standards, was selected by the Council as the new chairman and Bruce C. Netschert, vice president of the National Economic Research Associates, Inc., was elected vice chairman. Terms of the officers began July 1.

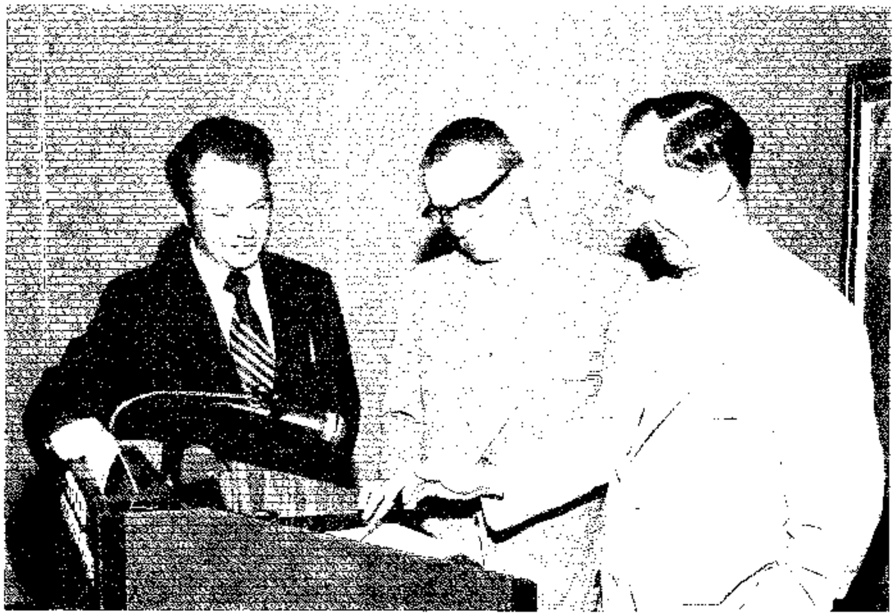
The appointment of two new Council members by EPRI's Board of Directors was announced during the meeting: Robert K. Bloom, a member of the Pennsylvania Public Utility Commission, and Marvin S. Lieberman, chairman of the Illinois Commerce Commission. They replace Erwin D. Canham, editor emeritus of *The Christian Science Monitor*, who has been named resident governor commissioner of the North Marianas, and Marvin R. Wooten, North Carolina Utilities Commission, who has accepted a North Carolina state judiciary post.

During the meeting, EPRI President Chauncey Starr and Planning Staff Director Richard Rudman presented an overview of the EPRI program and Dwain Spencer, director of the Advanced Fossil Power Systems Department, discussed the economic comparison of coal conversion alternatives. Members also attended a dinner at which Craig Smith, editor of the EPRI handbook *Efficient Electricity Use*, described the 18-month study that led to publication of the handbook.

The Advisory Council will convene August 16–20 in Aspen, Colorado, to participate in a seminar on the topic "Perspectives on Energy and Society."

A joint meeting of the Council and EPRI's Board of Directors is planned for November 4 at EPRI.

Lag in National Power Growth Analyzed



Emil Kasum (right), Philadelphia Electric Co., reviews material from a recent EPRI workshop with Gene W. Sellar (center), Dallas Power and Light Co., and René Malès, EPRI director of the Energy Systems, Environment, and Conservation Division. Kasum, a member of the ESEC Division Committee, and Sellar, a member of the ESEC Energy Supply, Demand, and Conservation Task Force, served as session chairmen for the Chicago workshop.

In 1974 and 1975 the national average growth rate of electric power showed a dramatic decline from the historical pattern. The causes of the decline have been variously attributed to a decline in the level of economic activity, a response to price increases, and non-price-related conservation. Acting to limit the decline were the rise in prices of competing energy sources and the lack of availability of natural gas in some areas, as well as consumer expectations about future prices and availability of other fuels.

Clarifying what happened was the purpose of a recent workshop sponsored by EPRI and EEI in Chicago. One afternoon was devoted to presentations analyzing power growth in the years 1974 and 1975 from a national and regional viewpoint. Speakers brought such diverse points of view as those of regional reliability councils, equipment manufacturers, economic research consultants, EPRI, the Federal Energy Administration, and the Federal Reserve Board.

The second day of the workshop was devoted to presentations by utility companies on the 1974–1975 experience in their territories. According to Milton F. Searl, manager of EPRI's Energy Supply Studies Program, these presentations revealed widely different growth patterns and, to some extent, different assessments of the strength of various factors influencing growth rates. Although no attempt was made to arrive at a consensus, it was clear that the low level of economic activity played a major role, and rising prices also contributed. Assessment of the extent to which non-price conservation effects were important (and were continuing) varied greatly.

The papers present a wealth of data for future analysis and will be published with a summary prepared by EEI.

Reactor Recirculation Pumps

The objectives and current status of projects being performed by Combustion Engineering, Inc., Babcock & Wilcox Co., Creare, Inc., and the Massachusetts Institute of Technology were presented at a recent two-day technical meeting held at Combustion Engineering, Inc.

According to Kjell Nilsson, project manager for the studies, the overall objective of these efforts is to improve the understanding of pump two-phase flow performance and to formulate an acceptable analytic model for use in loss-of-coolant accident analysis codes.

Forty-three representatives from the U.S. Nuclear Regulatory Commission, the Federal Ministry for Research and Technology of the Federal Republic of Germany, reactor vendors, EPRI project contractors, and member utilities attended the meeting.

A working group was established to periodically review and guide these projects, which are expected to be completed in early 1978.

A more detailed review of these projects is presented in the Nuclear Power Division R&D Status Report, page 29.

T&D Exhibit at IEEE Convention

The Transmission and Distribution Division will have an exhibit at this year's IEEE Underground Transmission and Distribution Conference planned for September 26–30 in Atlantic City, New Jersey. EPRI President Chauncey Starr will be the keynote speaker.

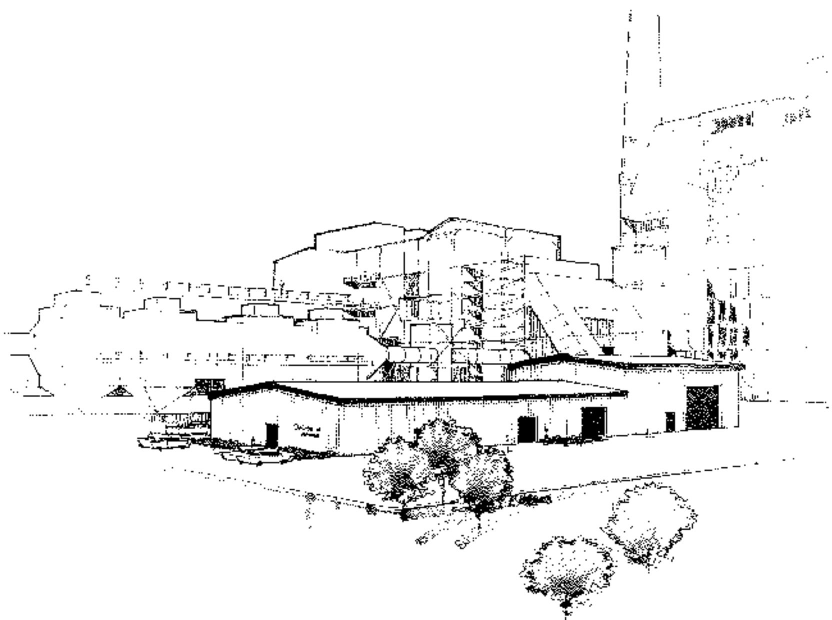
In addition to EPRI and ERDA exhibits, both research organizations are planning panel discussions on the status of their research programs in underground transmission and distribution. Coordinating these panel sessions will be H. Feibus of ERDA and Ralph Samm of EPRI.

Project Highlights

Testing Advanced Particulate Control Techniques

A $4 million advanced particulate control development and test center for advanced flue gas cleaning processes was recently announced by EPRI and the Public Service Company of Colorado (PSCC). The experimental station will be located at PSCC's Arapahoe power station in Denver.

The facility will contain pilot-scale electrostatic precipitators and equipment for evaluating high-temperature particulate removal techniques. The first tests will evaluate the effectiveness of a high-intensity ionizer (developed by Air Pollution Systems of Seattle, Washington, for electrostatic precipitators) and alternative high-temperature filter systems. In addition to EPRI and PSCC, participants include Combustion Engineering, Inc., to design and construct the facility; Flow Research, Inc., to design instrumentation and the data acquisition system; Joy Manufacturing Co., Western Precipitation Division, to supply the precipitators and operate the precipitator test programs; Stone & Webster Engineering Corp., to operate the high-temperature cleanup test programs; and Kaiser Engineers, to provide project management on behalf of EPRI.



Proposed advanced particulate control development and test center.

Test results performed at the center will assist utilities in solving difficult particulate control problems, especially those inherent in using low-sulfur, high-ash coals, and in improving fine-particulate collection efficiency.

Owen Tassicker, EPRI project manager for the center, said that in the next five years electric utilities may face expenditures approaching $5 billion to upgrade pollution control equipment. In anticipation of this, EPRI has initiated a broad program to evaluate many new techniques for improving the removal of particulates from flue gases before their discharge into the atmosphere. After bench-scale operations, many of these new techniques will be further developed and tested at the center to determine performance under actual utility operating conditions.

Upgrading Coal Liquids

Because supplies of domestic oil are decreasing, the electric utility industry has been sponsoring research into upgrading coal liquids for use as utility turbine fuels, reports William C. Rovesti, an EPRI project manager for coal liquefaction research. Utility turbines rely on petroleum-based fuels to meet peak electric power demands. If coal liquids could be economically upgraded, the electric utilities would have an alternative turbine fuel.

The unrefined products of two of the key coal liquefaction processes now being developed in the U.S.—H-Coal and solvent refining—although potentially suitable for utility boilers, would not be suitable for power turbines.

"What we are attempting to do at EPRI is upgrade these coal liquids so they meet the operational and environmental requirements of gas turbine fuels," Rovesti said, discussing a new phase of research in this area.

This $625,000 research effort is being cofunded by EPRI and Mobil Research and Development Corp. Project results are expected to provide important information for developing a processing model that can be applied for upgrading a wide variety of coal liquids.

Prior research characterized the chemical and physical properties of H-Coal, Synthoil, and solvent-refined coal liquids. It also suggested a preliminary definition of hydroprocessing requirements for upgrading these products to turbine fuels.

Goal for New Vacuum Interrupter

Raising the interrupting current and voltage-handling capability of a vacuum circuit interrupter from today's 45-kV, 50,000 A to 80-kV, 63,000–80,000 A is the goal of a $1.65 million research project recently awarded to General Electric Co.

Vacuum interrupters take advantage of the high dielectric strength of a vacuum to allow a reduction of mechanical effort in short contact travel, explained the manager of EPRI's Substation Program, Narain Hingorani.

In announcing the contract, Hingorani said vacuum interrupters have a long operating life, are extremely reliable, and are virtually maintenance-free. A successful project conclusion would provide the technology necessary to manufacture vacuum power circuit breakers that are competitive with other types of circuit breakers.

The development of these high-power circuit interrupters is expected to take approximately three years, according to Hingorani, who will manage the project with EPRI consultant Glenn Bates.

Study of Electricity Rates

Six electric utilities in addition to Virginia Electric and Power Co. have been selected to participate in the Electric Utility Rate Design Study. The six include Carolina Power and Light Co., The Dayton Power and Light Co., Minnesota Power and Light Co., Omaha Public Power District, Portland General Electric Co., and the Tennessee Valley Authority. Operating records supplied by the utility participants are being used to determine the effects of various costing and pricing approaches.

In announcing the selection of these utilities, project director Robert G. Uhler said that both rate design personnel at the utilities and members of state regulatory commission staffs are periodically reviewing the research.

"The seven utilities were selected because they represent different and—in certain cases—unique operating characteristics in regard to generation mix, load curves, load factors, and customer class mix," stated Uhler. He added that in studying time-of-use pricing it is especially important to have utilities with summer and winter peaks and with different plans for future expansion.

"To assess alternative ways of costing, setting rates, and picking load controls, many operating conditions have to be recognized," said Uhler. "The impact of new rate concepts should be analyzed, using actual company experience."

For example, Uhler noted that the consequences of basing rates on long-run marginal costs will be affected by a particular company's system expansion plans. Similarly, the cost-effectiveness of different rate forms, metering configurations, and load management options will also be greatly influenced by the characteristics of an individual utility.

Preliminary studies of the seven utilities are scheduled to be completed this summer. Shortly thereafter, the Project Committee of the Electric Utility Rate Design Study will transmit the findings to NARUC in a progress report.

Electric Field Effects on Animals

EPRI and ERDA have joined in sponsoring a two-year, $2.3 million project to study the effect on animals of exposure to electric fields from high-voltage transmission lines. Electric fields are measured as voltage gradients in kVm, a measurement taking into account both voltage and line-to-ground distance.

Harry Kornberg, EPRI project manager, explained that EPRI will study electric field effects on large animals, whereas ERDA will study the effects on small animals.

"EPRI's participation amounts to $1.1 million and a contract has been awarded to Battelle, Pacific Northwest Laboratories to investigate the possible biological effects on Hanford miniature swine of long-term exposure to electric fields of 30 kV/m," Kornberg stated. "That's equivalent to 15 kVm of exposure for a human being and almost twice the intensity of a field any human would be exposed to from transmission lines in the U.S. today."

The maximum ac transmission voltage in the U.S. today is 765 kV. This can produce a 9-kV/m electric field directly under the lowest point of the transmission line. "A single, isolated conductor carrying 500 kV, 40 ft above the ground generates roughly the same voltage gradient at ground level as a similar conductor carrying about 1000 kV at an elevation of 80 ft," Kornberg explained. "Gradients from power lines may be compared with natural as well as other man-made electric fields. For example, beneath thunderclouds, 3kV/m and more have been measured."

In response to concern that exposure of humans to high-voltage electric fields may have harmful biological effects, a number of studies have been conducted recently in the United States and abroad. Kornberg noted, however, that many researchers have measured reactions in their subjects that may have been caused by intermediary conditions rather than by electric fields.

"Although the great bulk of evidence

suggests that there are no observable biological effects of electric fields from extra-high-voltage transmission lines," Kornberg stated, "there is a great need for carefully controlled research to identify subtle and elusive effects—if, indeed, any exist—caused by electric fields in biological material."

The Battelle experiment will involve 40 swine kept in four modules with electrodes activated 24 hours a day. There will also be a control group of 20 swine identically treated in all respects except that they will not be exposed to the electric field. An interdisciplinary team of biologists, physicists, biostatisticians, electrical engineers, biochemists, and behavioral physiologists will monitor the experiment.

ERDA's part of the project has also been contracted to Battelle. It will involve research on small animals, such as rats, mice, and hamsters.

EPRI Negotiates 26 New Contracts

No.	Title	Duration	Funding ($000)	Contractor/ EPRI Project Mgr.
Fossil Fuel and Advanced Systems Division				
RP724-1	Flue Gas Conditioning for Enhanced Precipitation of Difficult Ashes	9 months	86.0	Southern Research Institute *W. Piulle*
RP725-4	Advanced Particulate Control Development and Test Facility	3 months	71.0	Joy Manufacturing Co. *O. Tassicker*
RP733-1	Ozone Dosage and Contracting for Condenser Biofouling Control	2 years	218.0	Public Service Electric & Gas Co. *J. Maulbetsch*
RP734-1	Acoustic Emission and Vibration	2 years	244.4	Rockwell International *H. Swenson*
RP737-1	Design for a Pilot/ Demonstration Compressed Air Storage Facility Employing a Solution-Mined Salt Cavern	5 months	85.0	General Electric Co. *J. Pepper*
RP781-1	Comparison of Fine Particulate Measurement Techniques for Source Testing	9 months	34.6	M. J. Pilat, Inc. *R. Carr*
Nuclear Power Division				
RP497-2	Modification to the Computer Code EPRI-CPM	1 month	8.2	Studsvik AB Atomenergi *B. Zolotar*
RP514-1	Fast Reactor Blanket Designs	3 years	200.0	Purdue Research Foundation *R. Sehgal*
RP601-1	Methodology for Plastic Fracture	20 months	289.9	Battelle, Columbus Laboratories *R. Smith*
RP605-1	Evaluation of Defect Characterization by Ultrasonic Holography	26 months	232.1	Babcock & Wilcox Co. *K. Stahlkopf*
RP611-1	PWR Fuel Performance Project	39 months	1914.0	Westinghouse Electric Corp. *F. Gelhaus*
RP612-1	Cross-section Sensitivity Analysis for Thermal Lattice Parameters	6 months	45.0	Union Carbide Corp. *O. Ozer*
RP711-1	Cooperative Program on PWR Fuel Rod Performance	38 months	1066.0	Babcock & Wilcox Co. *J. Roberts*
RP767-1	Probabilistic Reactor Safety and Risk Analysis	2 years	1114.0	Science Applications, Inc. *G. Lellouche*
RP769-1	Performance Measurement System for Training Simulators	1 year	201.2	General Physics Corp. *R. Pack*
RP770-1	Development of Adaptive Techniques for Pipe Inspection	17 months	241.3	Adaptronics, Inc. *G. Dau*
RP722-1	Dosimetry Measurements of Neutron and Gamma-Ray Fluxes in the Reactor Cavities of LWRs	20 months	131.7	IRT Corp. *F. Rahn*
Transmission and Distribution Division				
RP751-1	Analysis of Transients on Transmission Systems	26 months	631.2	Westinghouse Electric Corp. *S. Nilsson*
RP751-2	Analysis of Transients on Transmission Systems	36 months	None	Florida Power & Light Co. *S. Nilsson*
RP754-1	Development and Evaluation of a High-Power Vacuum Interrupter Prototype	37 months	1650.0	General Electric Co. *N. Hingorani/ G. Bates*
Energy Systems, Environment, and Conservation Division				
RP434	Electric Utility Rate Design Study	8 months	65.0	Arthur D. Little, Inc. *R. Uhler*
RP434-7	Electric Utility Rate Design Study	8 months	27.0	J. W. Wilson & Associates, Inc. *R. Uhler*
RP434-10	Electric Utility Rate Design Study	6 months	34.9	Power Technologies, Inc. *R. Uhler*
RP677-2	Air Quality Modeling	4 months	19.6	Flow Research, Inc. *C. Hakkarinen*
RP756-1	Vegetative Succession Related to Transmission Facilities in Semiarid Areas	2 years	29.0	Public Service Co. of New Mexico *R. Goldstein*
RP799-1	Electric Field Effects on Large Animals	2 years	1125.4	Battelle, Pacific Northwest Laboratories *H. Kornberg*

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.

New Publications

Energy Systems, Environment, and Conservation

EPRI SR-41 PROCEEDINGS OF THE WORKSHOP ON SAMPLING, ANALYSIS, AND MONITORING OF STACK EMISSIONS
Special Report

This special report presents the proceedings of an EPRI-sponsored workshop held in Dallas, Texas, in October 1975. Among topics discussed were the continuous monitoring for particulates (opacity) and for gaseous emissions (sulfur dioxide and nitrogen oxides) in stack gases from coal-fired electric power plants and special sampling and advanced analytic techniques for these materials, along with the problems encountered by users. The report outlines federal emission monitoring regulations and standard EPA and ASME methods for stack gas monitoring, sampling, and analyses. Established measurement techniques, as well as those being developed, are also covered.

Collaborative tests show that techniques for measuring sulfur dioxide and nitrogen oxides (EPA methods 6 and 7) and for measuring particulate emissions (EPA method 9) for visual estimation of opacity have precisions of 5–10%. The precision with which particulate matter can be measured (EPA method 5) has not yet been established.

R&D needs in stack gas measurements were reviewed, such as improved techniques for sampling particulate matter in flue gas downstream from wet scrubbers and better information about particle size and morphology. Reviewed also were advanced techniques for the continuous measurement of mass particulate emissions, as by the attenuation and scattering of light, the deposition of particles of electrical charges, the attenuation of beta radiation, and the effect of deposited particles on the vibrational frequency of a quartz crystal.

The report contains a record of the discussions held after the presentation of each paper and reviews practical problems encountered in the field and their solutions. *Southern Research Institute*

EPRI EC-131 EFFECTS OF ELECTRIC FIELDS ON LARGE ANIMALS: A FEASIBILITY STUDY
Final Report

Research is needed to demonstrate clearly whether electric fields from existing and proposed transmission systems have detectable effects on living systems and if such effects exist, to provide a plan for establishing an improved data base by which safe exposure limits may be defined. EPRI has contracted Battelle, Pacific Northwest Laboratories to investigate the possible biological effects to Hanford miniature swine (HMS) of long-term exposure to 60-Hz electric fields.

Experiments were conducted to determine whether HMS could be exposed to large electric fields without adverse effects and to determine the upper limit on field strength that would not produce corona (hence ozone) on or near the animal, minishocks, or hair stimulation. The behavior of the swine appeared normal at field strengths up to 50 kV/m. At 55 kV/m, ear flicking was commonly observed. No corona occurred on or near the swine at field strengths up to 55 kV/m. The threshold field strength for piloerection and hair oscillation was about 50 kV/m. Experimental evidence was obtained indicating that HMS may perceive electric fields at 30–35 kV/m without visible hair movement.

Electric field measurements were made with and without HMS to assess perturbations introduced by them. As expected, the field was markedly altered in the vicinity of the HMS.

The report details recommendations for more complete dosimetry in order that results from studies with experimental animals may be used as a data base for establishing human exposure limits. *Battelle, Pacific Northwest Laboratories*

Fossil Fuel and Advanced Systems

EPRI 108 PLASMA HEATING AND CONFINEMENT WITH HIGH CURRENT RELATIVISTIC ELECTRON BEAMS IN A TORUS
Final Report

This work investigates the usefulness of intense relativistic electron beams for confining and heating plasma in toroidal geometry.

Some of the major accomplishments of the program include the theoretical development of drift trajectories, including the effects of conducting walls in straight and curved geometry, along with experimentally observed confirmation; injection of up to 60% of the diode energy into the racetrack containing neutral gas, using an external field shaping cathode; and observation of the propagation of the beam one time around the racetrack at 200 microns, showing additional agreement with the zero-order drift predictions. *Cornell University*

EPRI 223-1 THE FORMATION OF NITROGEN OXIDES FROM FUEL NITROGEN
Final Report

Nitrogen oxides (NO_x) are one of the principal pollutant species emitted from combustion sources. Two major routes exist for the formation of NO_x: one through the oxidation of atmospheric molecular nitrogen (thermal NO_x) and the other through the oxidation of nitrogen containing compounds in the fuel (fuel nitrogen NO_x). The amount of fuel nitrogen contained in fossil fuel can vary considerably, with negligible amounts in natural gas, significant amounts in distillate fuels, and amounts from 0.5% to 3% in residual fuels, coal, and coal-derived and shale-derived fuels. The amount of fuel nitrogen NO_x produced in combustion processes increases with the fuel nitrogen content of the fuel.

Although NO_x production from fuel nitrogen species has been the object of several recent studies, the mechanism is not well understood and product nitrogen species frequently have not been identified and accounted for quantitatively. Similarly, the reactions of NO_x in combustion processes are poorly understood. The present study is a step toward increasing the understanding of the chemistry of fuel nitrogen and oxides of nitrogen reactions in combustion environments. The ability to account quantitatively for all of the nitrogen is essential and has constituted a major part of this effort. The report also includes a review of other studies of fuel-nitrogen chemistry, nitrogen compound measurement, and premixed flame experiments. *University of California, Berkeley*

EPRI 361-1 UPGRADING OF COAL LIQUIDS FOR USE AS POWER GENERATION FUELS
Phase 1 Report

Large-scale pilot plants for the liquefaction of coal have been successfully operated, and demonstration plants are being constructed. Because coal liquids are expected to become commercially available during the 1980s, it is important to establish their suitability as power generation fuels.

This report describes the results of Phase 1 of a study on upgrading coal liquids for use as gas turbine fuels. The primary objectives were to identify process and quality problems that exist in using raw and processed coal liquids as gas turbine fuels and the compatibility problems in blending coal liquids with conventional petroleum fuels. Also, the results of Phase 1 are to be used as the basis for recommendation for further work. As part of Phase 2, a cooperative effort with one or more turbine manufacturers will evaluate the performance of the raw and processed coal liquids as gas turbine fuels. Small-scale laboratory tests will be used. *Mobil Research and Development Corp.*

EPRI 366–1 CHARACTERIZATION OF MINERAL MATTER IN COALS AND COAL LIQUEFACTION RESIDUES
Annual Report

This investigation seeks to characterize the mineral matter and the organic fractions of coals and liquefaction residues. Correlations will be sought between the composition and properties of these materials and specific liquefaction process phenomena. As the characterization of mineral matter is important to liquefaction and to the entire range of coal utilization, the program's objective is to determine both the chemical and petrographic composition of samples and also the size distribution of these insolubles.

The report presents both critical evaluations of each technique, including application, limitations, and reproducibility, and also the findings for the samples received. *The Pennsylvania State University*

Nuclear Power

EPRI NP-128 TWO-PHASE PUMP PERFORMANCE PROGRAM: PRELIMINARY TEST PLAN
Key Phase Report

The basic objectives of this model pump test project are (1) to obtain sufficient steady-state and transient two-phase data to substantiate, and ultimately improve, the mathematical model of the reactor recirculation pump presently used for LOCA analysis and (2) to obtain sufficient data on pump overspeed characteristics under transient two-phase blowdown conditions to verify pump flywheel integrity.

The preliminary test plan report presents the test matrix and the background and logic that went into its formulation. Both steady-state and transient testing will be performed on a one-fifth scale model pump. *Combustion Engineering, Inc.*

EPRI NP-143 AN EVALUATION OF STATE-OF-THE-ART TWO-VELOCITY TWO-PHASE FLOW MODELS AND THEIR APPLICABILITY TO NUCLEAR REACTOR TRANSIENT ANALYSIS
Final Report

EPRI sponsored this state-of-the-art review in order to provide the nuclear industry with a publicly available assessment of two-velocity thermal-hydraulic models and their applicability to nuclear reactor technology.

The term *two-velocity model* generally refers to a model that utilizes separate conservation equations for the liquid and vapor phases of a two-phase fluid. In contrast, the commonly used *homogeneous equilibrium model* treats the fluid as a homogeneous two-phase mixture. The significance of treating both phases individually is that the resulting theory, being more physically realistic, is capable of describing a much larger set of problems within a single theoretical framework.

The two major objectives of this evaluation were to document the basic theory in a consistent self-contained report and to apply a prototype two-velocity code (UVUT) to a limited number of separate effect tests. The results of this study are presented in three volumes: Volume 1 is a summary of the entire effort; Volume 2 contains the theoretical basis of the two-velocity models; and Volume 3 presents the data comparisons.

As this state-of-the-art review concentrates mainly on the effort with which the authors were associated, it may not be all-inclusive and its models are still in a state of evolution. *Energy Inc.*

EPRI NP-159 REVIEW AND ANALYSIS OF STATE-OF-THE-ART OF MULTIPHASE PUMP TECHNOLOGY
Technical Report 1

This report reviews the technologies that bear on the fluid dynamics of multiphase flow pump behavior. It discusses these topics: pump flow physics; scale modeling of single-phase and two-phase pump operation, existing empirical two-phase pump data; piping network flow regime characteristics; and unsteady and oscillatory pump/loop system characteristics.

Emphasis is placed on the development of an understanding of two-phase pump behavior to determine the adequacy of scale model tests (both steady-state and transient) to predict full-size, primary coolant pump LOCA characteristics. Also emphasized are the requirements for adequate LOCA code development. *Creare Inc.*

EPRI 500-1 PHASE I IMPROVEMENT OF NUCLEAR REACTOR COMPONENT MATERIALS BY APPLICATION OF HOT ISOSTATIC PROCESSING (HIP)
Survey Report

This report summarizes the results of an EPRI-sponsored state-of-the-art survey of hot isostatic processing (HIP). The purpose of the study was to identify potential nuclear plant applications of HIP with high payoff through improvement in component quality and reliability.

The survey shows that HIP will reduce cost and manufacturing time and improve quality and ease of nondestructive examination (NDE) of all castings for which porosity is a problem. Nuclear valves are a prime example. Tubing, pipe, and sheet and bar present other possibilities of somewhat less immediate promise. *Battelle, Columbus Laboratories.*

Transmission and Distribution

EPRI TD-126 DEVELOPMENT OF A FOAMED GLASS POWER POLE DERIVED FROM FLY ASH
Final Report

EPRI has sponsored a project to validate the application of a new technology using waste glass and fly ash that would provide an effective and economic power pole substitute. The new material, foamed glass, can be readily fabricated in any form, is nonflammable and impervious to chemicals, and is an electrical insulator with extreme longevity. A two-phase research activity was conceived by EPRI, first, to establish the new material's suitability to the power pole environment and second, to develop a pilot process and produce full-scale poles. This report presents the findings of Phase 1.

Foamed glass displays a wide variety of properties primarily dependent on its density. It has been used commercially for light-weight thermal insulation but never previously for load-bearing cylindrical foamed glass poles of high density. Phase 1 was primarily concerned with production and testing, and also with full-scale pole design, production costs, and fly ash utilization.

The results indicate that an 18.28-m (60-ft), Class 1 power pole can be made from foamed glass with fly ash filler for about $77 in a 220-t/day glass facility. If 20% of the utility pole market is satisfied by foamed glass poles, a savings of more than $100 million per year is possible. This would also have the effect of using more than one million tons of two underutilized resources: fly ash and waste glass. *ECP, Inc.*

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