Progress in Solar Cells

ELECTRIC POWER RESEARCH INSTITUTE

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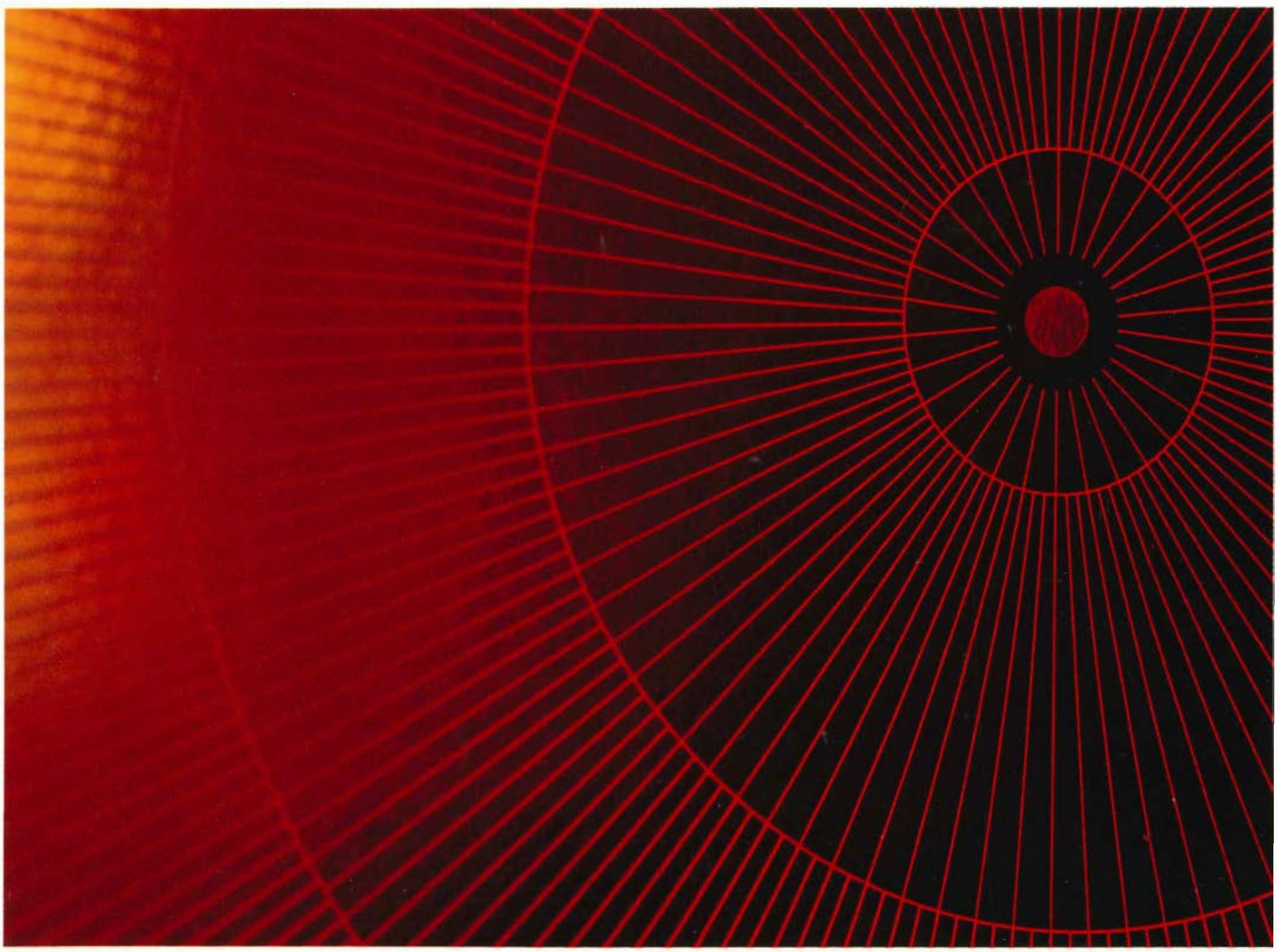

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Cover: Solar cells are the basic generation units in photovoltaic power systems. The rings and radii are metallic pathways that collect electric current from photovoltaic energy transformations in the cell.

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Photovoltaics: The Excitement Is Still There

Over the past decade, the quest for alternatives to an unacceptable dependence on imported oil has seen billions of research and development dollars spent on a seemingly endless array of renewable resource applications. Solar energy attracted the greatest attention among the renewables, and of all the options, none has engendered an excitement equal to that for photovoltaics. The apparent simplicity, modularity, and environmental acceptability of solar cells worked together to develop an avid and widespread following.

The emergence of photovoltaics as a space-age technology with proven performance as a satellite power supply seemed to imply that efficient terrestrial applications couldn't be far behind. Entranced with the then-popular idea that "small is beautiful," solar visionaries proclaimed the imminent arrival of personal energy independence through practical rooftop solar cell systems. Clearly this most optimistic scenario did not develop. As is often the case with early research, the inverse law of the value of ignorance was at work: the less one knows about an application and the world it has to fit into, the less expensive it seems to be. The cost estimates that followed with further work led researchers to adopt more realistic expectations.

Rooftop systems may, in fact, never become an economic reality, but this does not mean photovoltaics has no place in our energy future. The research dollars have taught us a lot about renewables in the last 10 years, and of the options that have survived the rigorous R&D culling process, there still remain serious contenders for economic and commercial acceptance; photovoltaics is one contender that is still very much in the running. What is becoming increasingly obvious, however, is that for solar cells to make a significant impact on electricity production in this country, they will have to go beyond the specialized, dispersed, and novelty applications that account for virtually all present use of photovoltaic devices. They will have to go for the real thing: bulk electric power generation.

Spurred by the current administration's redirection of federal R&D policy, during the past year EPRI has undertaken a broad-based effort to reassess the state of the art of photovoltaic research, the potential for future commercial applications, and

EPRI's role in the R&D process. Quite early in the assessment it became evident that there were photovoltaic device concepts that did indeed hold promise for achieving the performance and cost goals required for utility central power applications. What is more, the experts making up the study team reached a consensus on which paths held the greatest promise.

The state-of-the-art exercise made it clear that the economies of mass production, long thought to be the key to meeting cost goals for photovoltaics, cannot solve the problem alone. The real key to success still lies in achieving significantly better cell efficiencies than have been demonstrated to date. The current generation of solar cells are too inefficient and expensive to compete with existing power technologies. This supports the contention that we are still at the *R* end of the R&D spectrum and that the focus of research should be on improvements in the photovoltaic device itself.

The successful development path will most likely require several more years and considerable patience. In this respect, the commitment demonstrated by the private sector has been a very encouraging sign for commercialization of new photovoltaic devices. The interest and support is still in evidence, and improvements in efficiencies and manufacturing processes continue to be reported. Clearly, industry with private funding is becoming a dominant factor in photovoltaic development.

But basic research is a tougher road for industry than saturating existing markets with the technology now in hand. The R&D process must be protected from short-sightedness if the real challenge—a significant, ongoing market—is to be met. The options and promise are now before us. The question is whether the necessary momentum can be maintained.

John E. Cummings, Director
Renewable Resource Systems Department
Advanced Power Systems Division

Authors and Articles

Photovoltaics, an attractive possibility for electricity generation partly because it is expected to be cost-effective in small increments, may be doing well in R&D for the same reason. Advances are being demonstrated and validated quickly and inexpensively at small scale. **New Promise for Photovoltaics** (page 6) surveys a scene of heavy R&D action and surprising consensus. Written by Ralph Whitaker, feature editor, the article draws mainly on the findings of two EPRI research managers who recently conducted a specific assessment of photovoltaics R&D.

Edgar DeMeo has managed the Solar Power Systems Program since January 1980, guiding EPRI research in wind, solar-thermal, and photovoltaic energy technologies. He came to the Institute in August 1976 after a consulting assignment in thin-film photovoltaic technology. From 1969 to 1975 DeMeo was on the Brown University engineering research faculty; and for two earlier years, while a lieutenant in the naval reserve, he was an instructor in the science department of the U. S. Naval Academy. DeMeo graduated in electrical engineering from Rensselaer Polytechnic Institute in 1963; he later earned MS and PhD degrees at Brown University.

Roger Taylor joined EPRI in July 1980 as a project manager for photovoltaics R&D. From 1978 to 1980 he was with the Solar Energy Research Institute, working on the technical problems of integrating solar power technologies into electric utility systems. Between 1976 and 1978 he investigated similar problems for the research department of Arizona Public Service Co. Taylor has a BS in physics from Colorado College and an MS in mechanical engineering from the University of Arizona.

■

Source term, the radioactivity that might escape from various nuclear reactor accidents, has important implications throughout the plant design and regulatory processes. **Reactor Accidents: A Global Reassessment of Consequences** (page 16), by Taylor Moore, feature writer, reviews the many-sided research effort now under way to put rational upper limits on source term.

For technical assistance, Moore sought two EPRI staff members, Frank Rahn and Richard Vogel. Rahn came to the Nuclear Power Division as a project manager in August 1974. He later served as technical assistant to the division director and is now a technical specialist in risk assessment. Previously, Rahn specialized for nine years in nuclear cross-section research and reactor safety analysis, working successively for General Electric Co., Knolls Laboratory; Columbia University; Mathematical Applications Group, Inc.; and Burns and Roe, Inc. Rahn has a BS in physics from Queens College; he earned MS and DEngSc degrees in nuclear engineering at Columbia University.

Richard Vogel is a senior technical adviser and program manager in risk assessment for the Nuclear Power Division. He has been at EPRI since November 1980, on loan from Exxon Nuclear Co., Inc., until January 1983, when he became an Institute staff member. Vogel was with Exxon for 10 years, ultimately as director of research. Earlier, he was with Argonne National Laboratory for 24 years, including 10 years as director of the chemical engineering division. Vogel graduated in chemistry from Iowa State University. He has an MS from Pennsylvania State University, and he earned MS and PhD degrees in physical chemistry at Harvard University.

■

Someone finally did it—plug-in components for collecting electric load data from individual household appliances without rewiring. **An Electric ARM to Gather End-Use Data** (page 24) by Nadine Lihach, senior feature writer, is an account of a development that appears to be a winner in load research instrumentation.

Edward Beardsworth supplied technical information from his experience with the research since its inception. Beardsworth joined EPRI's Energy Analysis and Environment Division in June 1978, and much of his work for the Demand and Conservation Program has involved load research and modeling and the instrumentation for it. Previously with Brookhaven National Laboratory for four years, Beardsworth has a BS in physics from Northeastern University and a PhD in physics from Rutgers University.

■

Analysis of geothermal reservoir chemistry had a spotty record until EPRI's mobile laboratory took to the field.

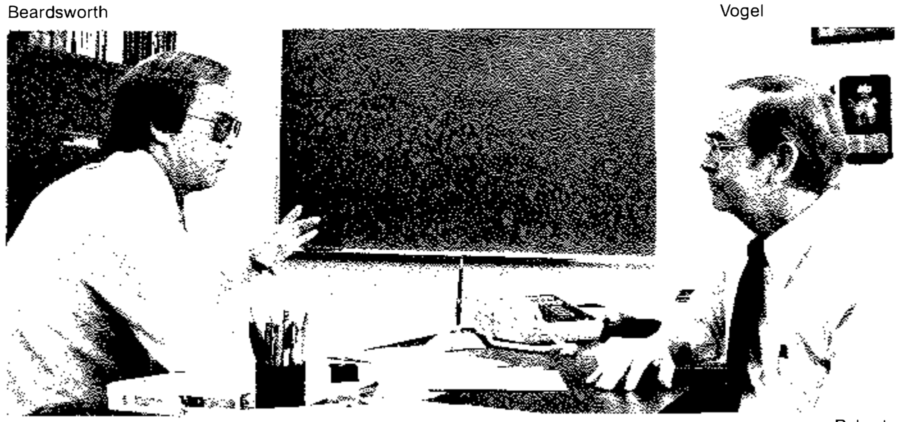
Geothermal Analysis at the Wellhead (page 28) explains how engineers are now using fast, accurate data to design around potential problems of scale and corrosion in geothermal power components. Ralph Whitaker wrote the article, with technical guidance from Vasel Roberts and James Jackson of EPRI's Geothermal Power Systems Program.

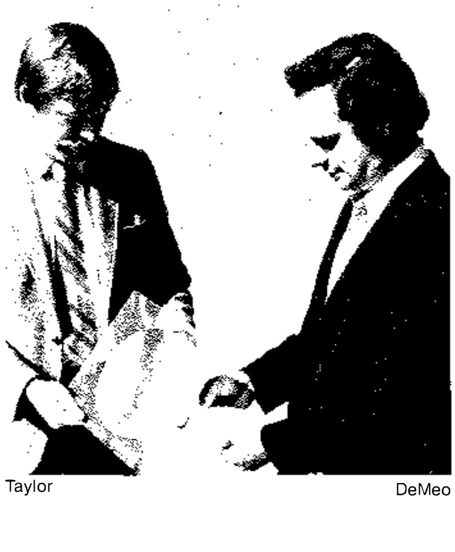
Roberts has managed geothermal R&D for EPRI since February 1975, his work concerned as much with the geothermal resource itself as with the power cycles for its use. Before 1975 Roberts was at the Jet Propulsion Laboratory (California Institute of Technology) for more than seven years. While there, he was responsible for the re-entry and landing systems of planetary exploration projects. He also worked on the commercial adaptation of various aerospace technologies. Between 1957 and 1967 he was a systems engineer on Sperry Rand Corp. missile and space vehicle projects. Roberts is a mechanical engineering graduate of the University of New Mexico.

James Jackson came to EPRI in June 1982 as a project manager in geopressure and minerals management research. During the preceding three years he was successively with SAI Engineers, and MCR Geothermal Corp. as chief chemical engineer and project engineer. From 1972 to 1979 Jackson was a systems engineer for the Nuclear Energy Business Operations of General Electric Co. He earned BS and MS degrees in chemical engineering at the University of California at Los Angeles.


Beardsworth


Vogel


Jackson Roberts


Taylor DeMeo


Rahn

New Promise for Photovoltaics

The attitude in today's photovoltaics research community seems to be not if, but when. Three approaches now have a better-than-even chance of meeting the cost and efficiency thresholds needed for bulk power generation.

Excitement is clearly showing up among the scientists working in photovoltaic energy R&D today. And that infectious quality is just one more reason to pay close attention to the technology, according to Edgar DeMeo, manager of EPRI's Solar Power Systems Program.

DeMeo and Roger Taylor, who manages EPRI's photovoltaics research projects, recently reviewed the many activities, projects, and findings of a year-long critical assessment of solar cell R&D. The two men see significance in the size and scope of industrial commitments, the identities of the participants, and the focus of R&D.

Most important, they find consensus on three promising approaches to photovoltaics: multilayer thin films of amorphous silicon, single-crystal silicon ribbon, and specially designed cells for use in concentrated sunlight.

The convergence of R&D thinking is a particular reason for optimism, DeMeo says. "There's a growing agreement that higher efficiency of energy conversion must be the main focus—not simply mass production economies.

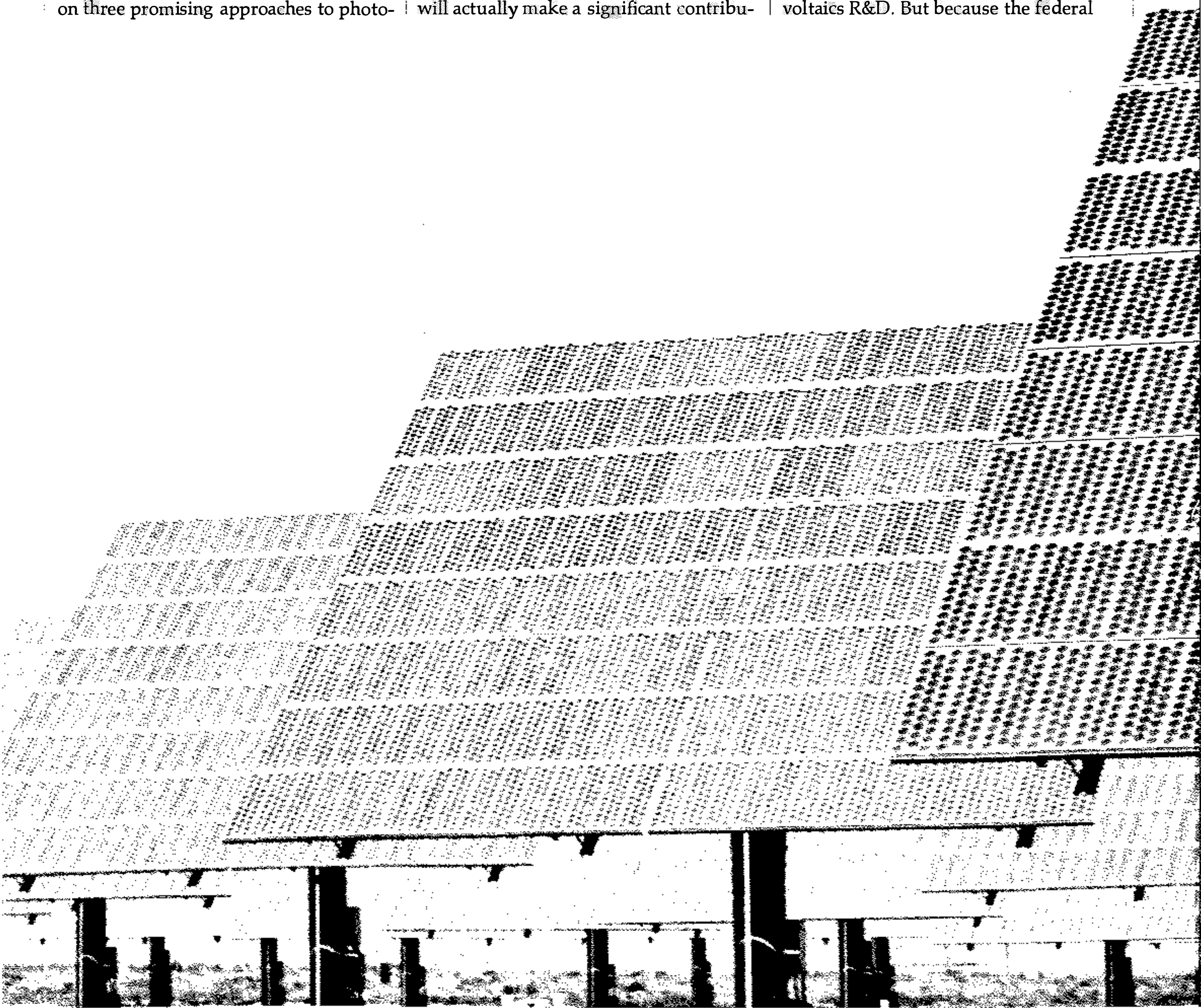
"Also," he adds meaningfully, "more people are seeing that the real carrot is the bulk power market: solar cells for electricity generation at utility scale."

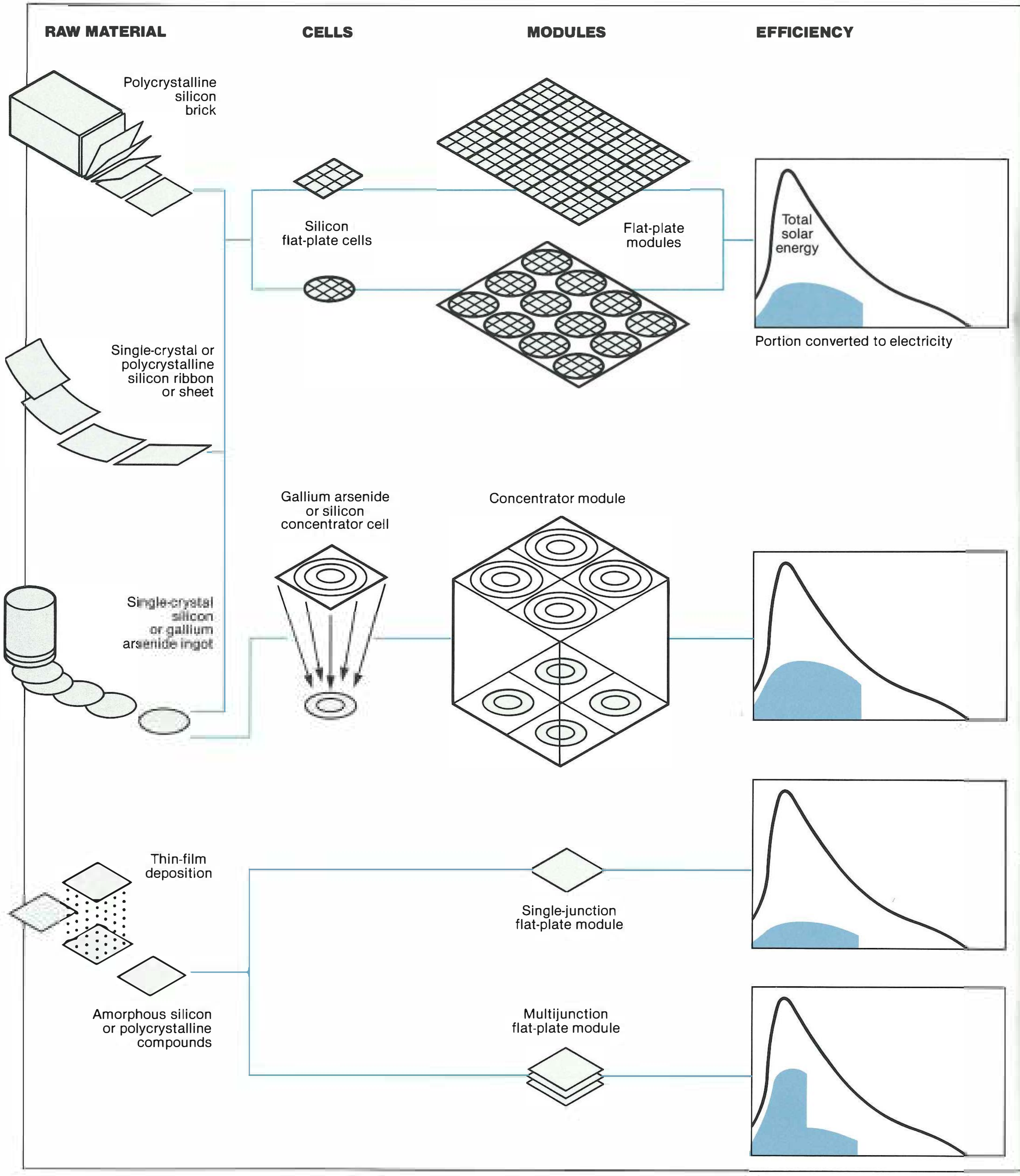
The conclusion is that photovoltaics may well expand beyond its present limited commercial use for remote-site power. There is reason to believe that it will actually make a significant contribution to U.S. energy supply. Far less certain is just when this will happen.

Glamor and technical targets

Solar cells have a persistent glamor: no moving parts, potentially long life, little perceived environmental impact, and inherent modularity; one can almost envision photovoltaic arrays manufactured by the mile and cut off to any desired installation size, from tens of kilowatts to hundreds of megawatts. Utilities see an opportunity to get useful increments of energy and meaningful experience in a new technology, both with relatively low financial and technical risk.

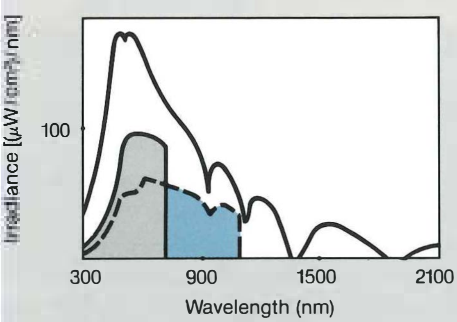
EPRI's recent assessment began as part of a continuing appraisal of photovoltaics R&D. But because the federal




RAW MATERIAL
CELLS
MODULES
EFFICIENCY
Polycrystalline silicon brick
Silicon flat-plate cells
Flat-plate modules
Total solar energy
Portion converted to electricity
Single-crystal or polycrystalline silicon ribbon or sheet
Gallium arsenide or silicon concentrator cell
Concentrator module
Single-crystal silicon or gallium arsenide ingot
Thin-film deposition
Single-junction flat-plate module
Amorphous silicon or polycrystalline compounds
Multijunction flat-plate module

In the most conventional cell manufacturing process, material is produced as a solid ingot or brick, which is sliced into wafers for cell fabrication. With newer processes, a continuous ribbon or sheet is drawn from molten material or a thin film is deposited on a rigid substrate. Some types of cell are more efficient than others, making use of more of the energy in sunlight. Two areas of intense interest for enhancing efficiency are concentrating systems, which take advantage of cells' greater efficiency at higher insolation levels, and multijunction cells, which use several layers of thin film, each of which draws energy from a select portion of the light spectrum.

Multijunction photovoltaic cells are a way to convert a larger fraction of solar energy to electricity. Solar radiation is distributed across a spectrum of wavelengths; the area under the curve represents the total energy of sunlight at the earth's surface. Each layer (each shaded



area) of a multijunction cell is treated to optimize energy conversion in a selected band of the spectrum and is essentially transparent to longer wavelengths. In effect, the multijunction approach allows a single unit to make use of wavelengths normally associated with several different kinds of cells.

photovoltaics program was changing so markedly in scope and emphasis, there was the special question of whether EPRI's program should be intensified. Two invitational workshops last winter were features of the overall appraisal. One was attended mainly by specialists in photovoltaic materials and devices; the other, by industrial managers responsible for development, business planning, and production.

The occasions became a two-way street. Participants gained a new understanding of utility industry needs and confidence in its purposes. EPRI staff members then and later established closer liaison with research managers in industry, government, and universities. The combination of efforts revealed several points of consensus and yielded new insights about the state of the art in photovoltaics.

Part of the consensus, to be sure, is that solar cell R&D continues with most of the same materials as it has had for the last several years. The best established is crystalline silicon, familiar from its long use as a semiconductor material. Most cells are produced as single crystals because this minimizes a phenomenon called recombination, which is most pronounced at grain boundaries and cuts electric output. Cells of relatively large-grain polycrystalline silicon are also being made, however.

Thin films (1–5 μm) are another R&D area. Because the energy content of sunlight is greater at some wavelengths than at others, researchers seek photovoltaic materials that offer a better match than silicon. Amorphous (noncrystalline) silicon is a candidate, as are gallium arsenide, cadmium telluride, and copper indium diselenide.

One other broadly defined R&D area is that of concentrating systems. Cell efficiency tends to increase with energy intensity, so R&D is under way to develop materials that best exploit this quality. Focusing-mirror and lens configurations are also of interest; and so are tracking mechanisms because solar concentrators respond only to direct sunlight and must therefore be aimed at the sun.

In all these areas there is a large unrealized potential between today's photovoltaic conversion efficiency and the theoretical limit. For single-crystal silicon in flat modules, as an example, the respective figures are about 8.5% and 20%. For silicon in concentrators, the figures are 20% (at about 30×) and 28% or more (at 500×).

But better efficiency does not stand as a technical challenge alone. It is an economic challenge as well, and this also motivates the convergence taking place today.

Pricing and payback

The historic stimulus for solar cell development, aside from successful early applications in space vehicles, was the energy crisis arising out of the oil embargo 10 years ago. The federal goal then, quickly matching a widespread popular vision, was to make solar cells cheap enough for consumers to use on houses and small commercial buildings.

Economical mass production techniques became the de facto industrial goal, but time has shown that it was held accountable for more cost cutting than could reasonably be achieved. The desired decline in average selling price slowed far short of its target values and dates. Thus, while solar cells still are not economical in consumer power applications, they are cheap and reliable enough to compete in (and even create) a number of high-value remote-power uses—telecommunications, navigational aids, and irrigation pumps, for example.

How photovoltaic systems are priced and sold, as well as what they cost, is also the subject of much new thinking. Multitier marketing and distribution costs are a significant increment of the consumer product price; they have the effect of holding prices up. Also, different markets take different views of cost amortization. For the most part, homeowners do not calculate payback; but when they do, they often use 3- to 7-year terms, as do a wide range of businesses and industries.

Electric utilities, in contrast, amortize plant investments on a life-cycle basis that may run as long as 20 or 30 years. Given predictable needs for energy over such a period, utilities can accept a higher price for photovoltaic equipment than users who must write off costs over fewer years. And utilities are a factory-direct market of large users.

There is one further, all-important condition for utilities. Photovoltaic power must be at least as cheap to own and operate on a life-cycle basis as any other generating option for the same mode of service.

This objective and the market it represents are now a powerful incentive for R&D into more efficient and reliable solar cells. Federal R&D plans endorse this perception, according to DOE's Robert Annan, division director for photovoltaic technology. "If photovoltaic electricity is to be a truly viable energy supply option in the 1990s—in either distributed or central station use—its cost will have to be on a par with electricity from competing alternatives."

Amorphous silicon

When EPRI's solar power staff get down to cases about photovoltaic research progress, three encouraging prospects (and one that is conditionally disappointing) compete for their attention, not only in discussion but in plans and recommendations for change in EPRI's own R&D sponsorship.

Amorphous silicon springs first to mind, partly because it is the subject of so much investigation. It is clearly a research subject for the next several years, despite a number of shorter-term commercial expectations other than bulk electricity.

Arco Solar Industries, Energy Conversion Devices (ECD), and RCA Corp. have been major U.S. researchers of amorphous silicon for solar cells. By building production equipment and licensing technology, ECD is involved in consumer product developments as well, both here and abroad. Japan is a major player; the government and several companies there are apparently cooperating as a unified R&D force. Xerox Corp. and others are also investigating amorphous silicon, which may improve speed and color receptivity in copiers and make possible easily re-recordable video disks.

The intense and widespread interest in amorphous silicon is exciting all by itself—and also significant because, as DeMeo says, "there is a critical-mass effect with research effort. Only when enough money and manpower are invested in a fairly consolidated effort can real advances be made—if," he adds cautiously, "the physical possibility is there at all."

Amorphous silicon has features that are already apparent. Its form avoids the complexity and cost of crystal growth; in fact, cells are conveniently deposited as thin films. Thick cells are not necessary because amorphous silicon absorbs solar energy much more readily than does crystalline silicon.

Efficiency in converting that solar energy to electricity is another matter. When first introduced, amorphous silicon did not show up well in this respect, and it has come from behind, in EPRI's opinion, only because it seems particularly amenable to use in multijunction cells. These have successive, selectively transparent layers, which are treated to convert different segments of the solar energy spectrum, thus yielding a greater overall efficiency for the cell area. The advantage of amorphous silicon is that it has no crystalline structure that must be matched up from layer to layer.

Efficiency figures for amorphous silicon define its status today and suggest its possible advance in the future. Single-junction cells in limited production are about 6–7% efficient, and laboratory results as high as 10.1% are reported for controlled areas less than 1 cm^2. Single-junction devices are likely to have a top limit of 12% in production.

Experimental multijunction cells have achieved 8.5% efficiency. Two- or three-layer devices may get to 16–18%, compared with a theoretical maximum of about 23%.

EPRI offers this quick summation of amorphous silicon as a prospective electric utility solar cell: medium probability of getting the necessary efficiency and reliability, high probability of meeting cost goals, and a development horizon perhaps exceeding 10 years.

Ribbon silicon

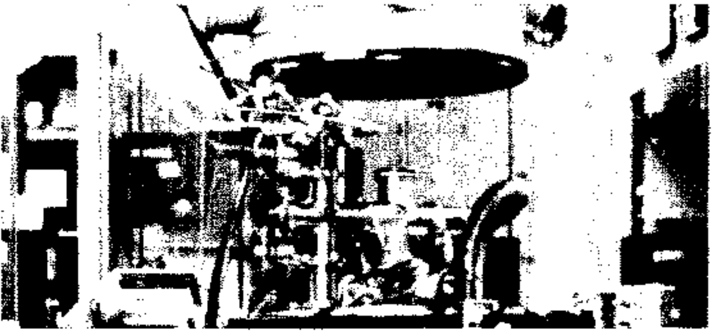
Another intriguing prospect in EPRI's assessment is an old standby, single-crystal silicon. The main attraction is not just the material itself, but how it is withdrawn and solidified from molten silicon as a continuous ribbon or sheet (instead of as discrete, sausage-shaped ingots that must be sawed into waferlike cells).

Single-crystal silicon is the mainstay of the commercial solar cell industry today. Included are such principal firms as Arco Solar, Mobil Solar Energy Corp., Solarex Corp., Solar Power Corp., Solavolt International, and Westinghouse Electric Corp.

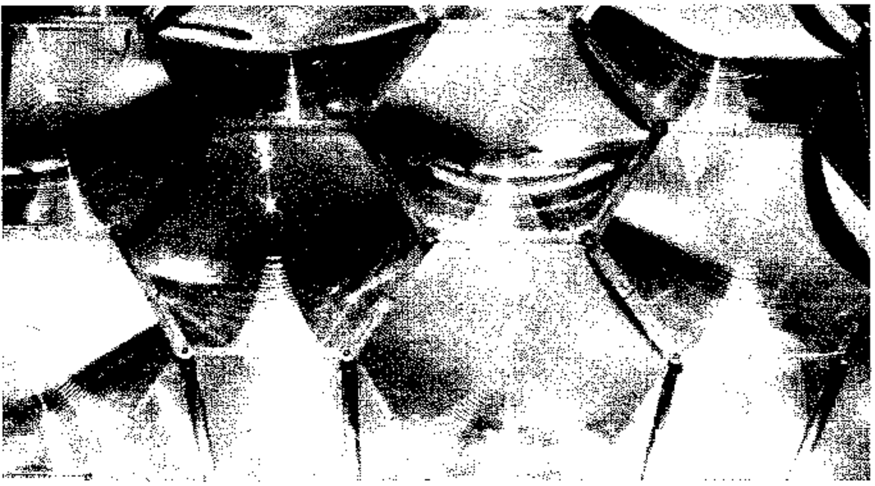
Ribbon silicon avoids the extra steps of sawing and polishing (and the consequent loss of material), but if it is to be developed, three critical questions have to be successfully resolved. One is how the ribbon can be pulled continuously from the melt over the long periods involved in mass production. Another question is whether it can be pulled fast enough to meet the economic requirements of an automated, low-cost manufacturing process. At issue is how quickly the ribbon can be cooled without building up intolerable stresses in the crystal structure.

The third question has research as well as production implications. Can high-efficiency cells, like those from sliced single-crystal silicon wafers, be processed from single-crystal silicon ribbon? Some evidence says yes, up to an efficiency of about 16–18%, which is as

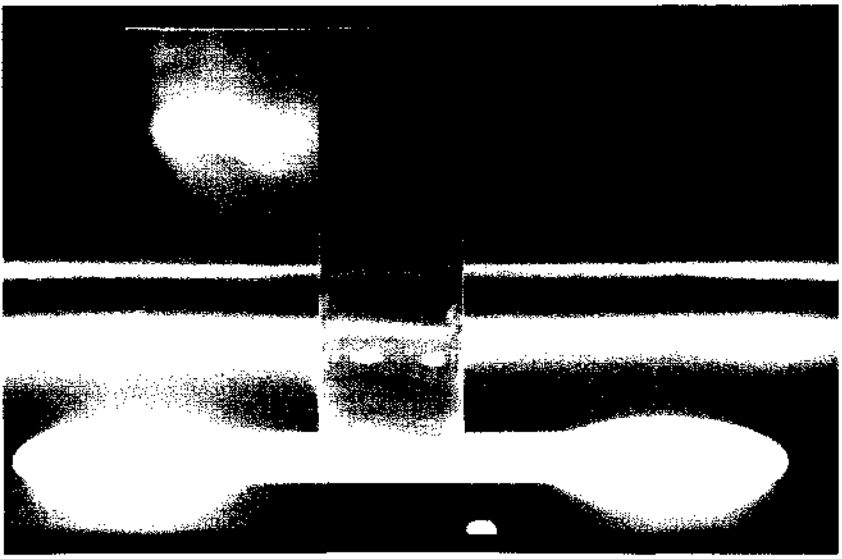
A glow discharge apparatus at the Solar Energy Research Institute is used to deposit sample thin films of amorphous silicon on rigid substrates.



Focusing lenses concentrate solar energy on small gallium arsenide cells in a 1000X passively cooled module made by Varian Associates.



Experimental equipment built by Westinghouse Electric Corp. allows highly refined silicon to be formed and solidified as an endless single-crystal ribbon.



good as or better than that of sliced cells.

When EPRI staff review the judgments of consultants and industry against their own experience, a summary prediction emerges for single-crystal silicon, especially in the ribbon form: high probability for attaining utility efficiency and reliability targets, medium probability for getting the cost down far enough, and reasonable expectation that the answers will be evident in fewer than 10 years.

Concentrating systems

Why not economize on solar cells by focusing more sunlight on each one? The idea works, but concentrating systems entail offsetting penalties and costs.

The most obvious advantage is that such systems require less cell area (less photovoltaic material). Not so obvious, but distinctly welcome, is that energy conversion efficiency improves with intensity. Concentrating cells are therefore more efficient than flat-plate cells, so the entire light-gathering system (the so-called aperture area) can be smaller for a given power rating.

Efficiency considerations are not completely clearcut, however. Concentrating cells also operate with higher currents, so electric resistance losses (as heat to be dissipated) become more important. To design around these characteristics means cells that are complex and costly per unit of area.

The lenses (preferred over mirrors) and solar tracking mechanisms required for concentrating systems should be less expensive than the equivalent area of flat-plate cells. And despite their complexity, solar cells for concentrating systems do not increase in cost in proportion to their concentration ratios. Cell cost should therefore become a small fraction of system cost.

R&D in concentrating systems has attracted several firms, some of them not otherwise heavily involved in solar cells. Applied Solar Energy Corp.; E–Systems, Inc.; Hughes Aircraft Corp.; Martin Marietta Corp.; and Varian Associates, Inc., are some of these. Silicon and gallium arsenide crystal cells and cells using an alloy of aluminum arsenide and gallium arsenide are being studied and tested. Under EPRI auspices, a Stanford University research team is working with silicon cells for operation under solar intensities of 500× and up, and findings there point to eventual cell efficiencies of 26–28%. The multilayer approach is also applicable to concentrating cells, which may thereby attain efficiencies higher than 30%.

Again considering the probabilities for satisfying utility industry criteria, EPRI's assessment concludes: high probability for the needed efficiency gains, medium-to-high probability for the necessary reliability, but only medium probability that costs can be cut sufficiently. The time span seems to be 10 years or less.

Polycrystalline thin films are a fourth specialty of solar cell technology that calls for attention. But DeMeo and others sense rather less long-term potential than they did even two years ago.

Commercial sales have ceased, and therefore there is little field experience to assess. Even in the laboratory, efficiency advances have been slow and uneven; and long-lived performance is questionable. However, some alloys, among them copper indium diselenide, may be selectively useful, perhaps even in multilayer configurations with other materials.

All in all, EPRI sees good probability for getting polycrystalline thin-film costs down, low probability for meeting efficiency and reliability criteria, and based on recent progress, an R&D interval of more than 20 years. Clearly, there is no "critical mass of R&D effort," in DeMeo's phrase, being brought to bear.

Criteria for utilities

The probabilities of R&D success in photovoltaics can be seen as purely technical challenges. But in fact, they all have implications for electricity cost. For U.S. electric utilities to displace an appreci-

EFFICIENCY: FULCRUM OF FEASIBILITY

Energy conversion efficiency is the traditional comparative measure for photovoltaic cells. Although EPRI's analytic studies also yield target criteria for the cost and reliability of components in utility service, efficiency seems to be the pivot on which economic feasibility turns.

In 1983 that pivot point is 15% or better for a routinely manufactured module (4–16 ft^2; 0.4–1.5 m^2) of flat-plate cells. Only six or seven years ago, the efficiency threshold derived from EPRI studies was 10%, a value that some people at the time thought was restrictive. Because today's threshold is considerably higher, it is important to account for the change.

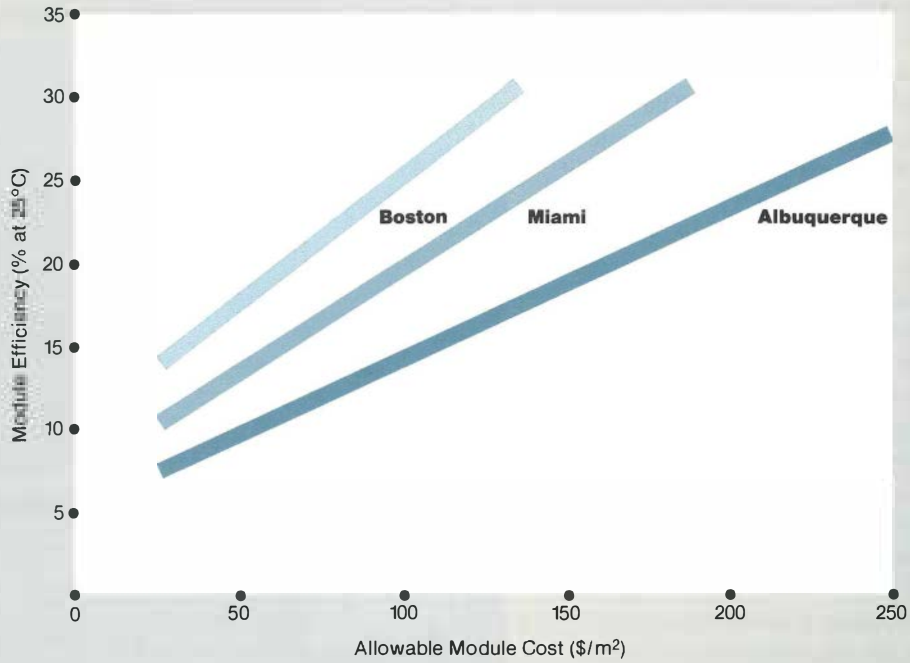
Foremost is more accurate knowledge of the nonphotovoltaic components of a system—the land, supporting structures, tracking mechanisms, panel connections, power-conditioning apparatus, installation labor, and so forth. Better understanding today tells developers (and EPRI) that these components cost more than previously estimated. Even if the solar cells themselves were totally free, a reasonable energy efficiency would be required; otherwise, the balance-of-system costs that depend on overall photovoltaic area would be so great as to disqualify the system from economic competition with electricity from other options.

The view of competing options has also changed in recent years, and this puts new demands on efficiency as a means to economy. It will not be enough for photovoltaics to compete solely with expensive electricity from oil-fired units. That only represents a price ceiling to be gotten under. Also, peak-period generation is not the competition. Peak electricity must be highly reliable, but electricity from solar cells is compromised by overcast skies, even by a chance cloud.

If photovoltaics is to penetrate the utility market appreciably (and displace significant energy), it must be efficient enough to compete against lower-cost, off-peak electricity—ultimately, the baseload output from new nuclear or coal-fired plants. Even energy storage does not necessarily tilt the balance to favor photovoltaics because storage can just as easily be charged from a baseload plant at midnight as from a photovoltaic array in midmorning.

Thus, energy conversion efficiency is the key challenge to photovoltaics in widespread utility service, and it is encouraging that several R&D approaches today appear equal to it. □

Better photovoltaic efficiency permits a higher cost for solar cell modules. As higher efficiencies are attained, smaller arrays can be used to produce a given amount of electricity, and because less money is needed for so-called balance-of-system items, such as support structures, more can be invested in the modules themselves. This relationship also depends on climate, with higher module cost allowable in Albuquerque, where the solar intensity is greater. These examples assume flat-plate systems that generate electricty for a levelized cost of 6.5¢/kWh (1982 $) and area-related balance-of-system costs of $50/m²$.



able quantity of other energy fuels by photovoltaics, stringent criteria for solar cell efficiency, reliability, and cost must be met.

Today, for example, flat-plate solar-cell modules are in the 8–10% efficiency range. The approximate target for utility purposes is 15%, according to studies done by Taylor. Reliability is roughly expressed in terms of a lifetime free from appreciable degradation. Many experts believe that today's modules will last for about 10 years, but photovoltaics must compete with the 30-year life of analogous components in other power technologies. Finally, flat-plate modules today cost about $500/m²$ in very large quantities—say, hundreds of kilowatts. That cost will have to come down to about $100/m²$. Concentrating modules will be able to remain somewhat more expensive—perhaps $150/m²$.

Taylor derived these figures from analytic studies (using data and models from utility systems) of the service role that solar cells can fulfill. The permissible cost for that role (and the competition a photovoltaic power plant must meet) is the least costly electricity available from another suitable technology.

The cost of the competitive technology, once it is defined, can be converted to an equivalent cost in photovoltaic components. Target figures for array efficiency, reliability, size, and cost are thereby derived. Improved solar cells will have to be considerably less expensive than those today, and they are also expected to exert cost-saving leverage on systems by reducing the requirement for structures and equipment.

Like other solar-based renewable energy options, photovoltaic power units do not get full capacity credit in their costing. That is, building such power units does not avoid retaining some increment of conventionally fueled generating capacity.

"In the near term," Taylor says, "the competition is likely to be an existing oil-fueled unit, perhaps a combined-cycle unit. But it could be another one of the newly developed renewables—wind, perhaps—or an alternative to all forms of generation, such as energy storage, load management, or conservation. The competition just isn't obvious."

Varying rates of progress

Surveying the state of solar cell R&D leads to several general conclusions, all of them necessary in planning the best moves for EPRI in bringing together the needs of electric utilities and the capabilities of photovoltaics.

For one thing, solar cell R&D is not a garage operation. The emphasis on materials and their performance requires resources and skill. So does the ever more aggressive effort toward more precisely reproducible units and automated mass production. Some of the smaller companies, highly product-specialized, may have a tough time competing with larger firms that can develop products, overhaul production lines, and conduct long-term research all at the same time.

Another forecast is that one photovoltaic technology will ultimately predominate, certainly in the large-scale market of electric utilities. The cell materials, number of junctions, production mode, method of concentration (if any)—none of these is yet clear, and in the meantime many varieties will compete successfully in the small, stand-alone power markets and in early grid applications.

The pace of market development will continue to be uneven, affected by the pace of other new technologies, world oil price and availability, government policies, and tax credits. Sales of remote-site photovoltaic systems are "paying the rent" while circumstances evolve. It will be interesting to see whether remote-power markets become saturated, and sales slacken accordingly, before improved cell efficiencies and reliabilities—and lower costs—open the doors to village power applications in developing nations and to the U.S. utility market.

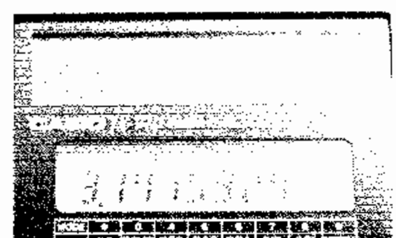
Federal R&D support has fluctuated with changes in administration perception and philosophy. Funding of specific efforts has often been only from year to year, justified on such specific bases as demonstrably better cell efficiency. Yet this may not be the most meaningful measure of advancement in photovoltaics R&D.

Private sector commitments have also wavered, frequently seeming to be ruled by the bottom line, the near-term profit that will hold management interest in an R&D venture. Currently, even without the immediate incentive of crisis in other energy resources, several companies investing in photovoltaics R&D are doing so rather methodically. They clearly accept long R&D intervals and distant commercial horizons.

Continuity and measurement

The uncertain course of events underscores the importance of trying to estab-

Too expensive for bulk electricity generation, today's solar cells find use mostly in applications remote from any grid. Consumer specialty items, such as solar-powered calculators, make up the remaining 25% of a current 8-MW worldwide annual volume. Large-scale applications will depend on a new generation of higher-efficiency photovoltaic devices.



lish R&D continuity. Continuity is a crying need in photovoltaics and one that EPRI sees some possibility of aiding. One objective of the Institute during the past 10 years has been to be an effective stabilizing and pacing influence in U.S. energy R&D.

DeMeo muses that the research management community needs a more flexible measure of R&D progress, some index that recognizes increased understanding of the many chemical, electronic, and optical features of photovoltaic materials, not to mention the processes by which they are combined for application. "We need to work at a problem long enough," says DeMeo, "for individual advances to aggregate into clear performance improvements.

"This will lead to something else," he adds. "If researchers sense that there really is commitment on the part of funding agencies and corporate managements, then more of the really best R&D talent will be applied to photovoltaics."

Right now EPRI staff are developing recommendations for a shift and an overall increase in EPRI's photovoltaics research sponsorship. Their choices parallel the consensus already described, the R&D avenues most likely to benefit from augmented effort: the quest for better efficiency, mostly in multijunction amorphous silicon cells; resolution of the ribbon silicon questions of producibility and heightened efficiency; and concentrating cells, which EPRI managers note have been funded within their program for some years.

Because of the critical mass of amorphous silicon R&D and the near-term significance of ribbon silicon, DeMeo and Taylor are anxious that any important omissions in the R&D be identified and covered. Such complementary work would include both university research (emphasizing photovoltaic phenomena and their mechanisms) and corporate research (closer to product development and application). EPRI experience as a coordinator of technology demonstrations encourages DeMeo to see the Institute as a participant or as a catalyst in some multiparty program centered on amorphous silicon, ribbon silicon, or concentrator technology. "If the basic questions generate favorable answers," he says, "the necessary venture capital will probably flow."

EPRI's attitude about photovoltaics is confident and optimistic: confident about what are the most important R&D needs, optimistic about what will be their outcomes. Even so, DeMeo acknowledges that EPRI's own role depends on many other R&D planning factors. The degree of EPRI's participation in the new research is not yet clear, but current plans call for closer involvement in each major area. ■

Further reading

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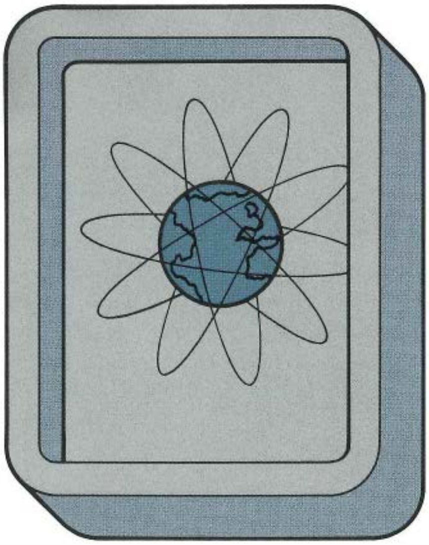
This article was written by Ralph Whitaker. Technical information was supplied by Edgar DeMeo and Roger Taylor, Advanced Power Systems Division.

REACTOR ACCIDENTS: A GLOBAL REASSESSMENT OF CONSEQUENCES

Three Mile Island has prompted a tough reappraisal of fission product release that will lead to a clearer perception of the public risk from nuclear power.



Three Mile Island's most important lesson may prove, in time, to be what did *not* happen on that March day in 1979. According to some prior estimates, about two million curies of radioiodine, the fission product isotope of most concern in human health effects, should have been released from the plant as a result of the accident. But in fact, postaccident measurements inside the reactor containment building showed the actual release to be at least a thousand times less than expected.

For the electric utility and nuclear power industries, government regulators, and the public, understanding the reason for such a wide disparity between predicted and actual effects of the accident carries profound implications. Has real-world evidence from TMI revealed that the radiation risk to the public from a nuclear plant accident is much less than previously assumed? More than half a dozen government and industry research programs are under way in search of a definitive answer to that question.

Elements of risk

Estimates of the public risk from nuclear power plant accidents hinge on three important factors.

- The probability of specific events occurring that could lead to an accident involving radiation release
- The quantity, type, and timing of release of radioactive material that would escape the reactor containment building if it is breached
- The effect of actions, such as evacuation, to mitigate the consequences of the accident to the public

The second factor—known as the accident source term—determines the severity of predicted consequences of a nuclear accident. If the source term for a postulated severe accident is overstated, the predicted consequences of the accident will be overestimated as well.

In the wake of TMI, regulatory requirements for emergency response planning in nuclear accidents were significantly enlarged. Yet the source term values used as a basis for these requirements bear no relation to the actual releases experienced at TMI; instead, they are the same values that have remained essentially unchanged and, until lately, unexamined for nearly 20 years.

There is a growing body of expert opinion worldwide that the source term values in use today are too large—perhaps by orders of magnitude. If that is true, utilities and government agencies may be planning for accidents that not only have a very low probability of occurring but in the unlikely event they do occur, will produce few of the acute health effects predicted under current source term assumptions. If the radiation release in a severe accident is considerably smaller or of a different kind than now assumed, it is possible that planning for mass evacuation of nearby residents lessens rather than enhances public safety.

Although many experts in the field of reactor safety analysis agree that current source term values are unrealistically large, there is much uncertainty over the extent to which the source term estimates could be prudently reduced with rigorous technical justification. This is a reflection of the complexity of the physical phenomena involved in a radiation release.

Filling the gaps in understanding the technical factors that bear on the source term in order to achieve a consensus for establishing more realistic source term estimates is the common goal of a diverse but complementary array of research programs being carried out in the United States and abroad by government and industry research groups. As a major sponsor of source term research, EPRI is working closely with regulatory agencies and other research institutions to resolve technical differences and to integrate the results of the work into a body of knowledge that will lead to improved understanding of the potential consequences of reactor accidents.

Separate laboratory-scale tests and analyses of fission product release from damaged fuel have already produced encouraging results. According to John J. Taylor, director of EPRI's Nuclear Power Division, "Excellent progress is being made and the results are confirming significant source term reductions that provide a basis for more realistic emergency planning guidance." From these individual tests will emerge predictive analytic methods and improved models. Large-scale integral experiments, in which the mechanisms of fission product behavior can be studied under simulated accident conditions, will be used to validate or correct the predictive analysis.

Understanding the origin of existing source term values and how they have evolved into the cornerstone of reactor safety design and regulation helps clarify the rationale for believing that they are unrealistic. A historical perspective also illustrates the difficulty involved in integrating new technical information on fission product release and transport within a political and regulatory framework that for years accepted the source term values as given.

The historical roots

The first published analysis of the potential consequences of a severe nuclear power plant accident was made by Brookhaven National Laboratory in 1957 for the Atomic Energy Commission (forerunner of NRC and DOE). The most severe postulated accident considered in the study, published as WASH-740, used as the source term the instantaneous release of 50% of the noble gases (xenon and krypton), 50% of the halogens (mainly iodine), and 50% of the solid fission products from the reactor core. Because little scientific information was available at the time, these release values were deliberately chosen high. Moreover, no analysis was made of how the fission products might be transported from the core to the containment and then to the outside atmosphere. A probability range of from one chance in a hundred thousand to one chance in a billion per year of reactor operation was discussed for the severe accidents considered in WASH-740, but no probabilities were assigned to specific accident scenarios.

With the need for plant design and site evaluation guidelines in the early 1960s, the concept of a maximum credible accident was adopted as a means for establishing an upper bound for the consideration of potentially severe—but very low probability—accidents. This maximum credible case was presumed to be a large loss-of-coolant accident (LOCA) resulting in reactor core meltdown and partial release of the fission product inventory in the core to the containment building and then to the outside atmosphere. An AEC technical document, TID-14844, was used to estimate the source term for this hypothetical accident.

The so-called TID source term is similar to the WASH-740 source term in that the accident scenarios are not specific and the physical processes involved in fission product release were not analyzed. The TID source term assumed that all the core inventory of noble gases and 25% of the iodine would be released from the core and reach the atmosphere outside the plant. A small amount (1%) of solid fission products was also assumed to escape the core region.

These values for a maximum credible accident source term were later incorporated in AEC safety guides, now referred to by NRC as Regulatory Guides, which the nuclear and utility industries follow in plant licensing applications and in emergency planning.

The next milestone in reactor safety analysis came in 1975 with the publication of NRC's well-known *Reactor Safety Study* (WASH-1400) directed by Norman Rasmussen of the Massachusetts Institute of Technology. A major advance in the state of the art of risk assessment, WASH-1400 was the first comprehensive attempt to use probabilistic techniques to estimate the chances and potential consequences of reactor accidents. Unlike previous studies, WASH-1400 analyzed specific accident scenarios and modeled some of the physical processes involved in radiation release. But to cover gaps in the data, the tendency even in WASH-1400 was to assume large fission product releases.

Most of the new analysis in WASH-1400 focused on the probabilities of accidents occurring; the source term assumptions for the risk-dominant accident scenarios were essentially the same as calculated 10 years earlier in TID-14844 and contained in the Regulatory Guides. But because the source term dominates the calculated consequences, the predicted effects in WASH-1400 of a severe plant accident would also be unrealistically high, as were those in the previous studies. Nevertheless, the Regulatory Guides and the WASH-1400 probabilistic risk assessment methodology—coupled with further worst-case assumptions regarding the dispersion of radiation into the atmosphere outside a damaged reactor—still form the basis for utility and government emergency preparedness planning.

Accident experience

Analysis of fission product release in past reactor accidents provides some insight on the degree that fission product releases may be overpredicted in current regulatory source term assumptions. The accident record shows that the presence of water and steam in the accident environment plays a key role in limiting the release of fission products, as well as in delaying the release of iodine. In a light water reactor (LWR), water is always present in the core under normal operating conditions and would be present along with wet steam even under damaged core conditions (as in the TMI accident, for example). In all LWR accidents and destructive tests involving water to date, no more than 0.5% of the available iodine has ever been released to the atmosphere and only limited quantities of other fission products have been detected in the environment.

The most noted of these accidents was at the stationary low-power reactor No. 1 (SL-1) in 1961 at the Idaho National Reactor Testing Station. A power excursion resulted in substantial core melting and release of fission products from the fuel. But despite the fact that SL-1, a 3-MW (th) prototype military reactor, was housed in an ordinary sheet metal building vented to the atmosphere, less than 0.5% of the iodine in the core reached the outside of the building. In all, only about 0.1% of the total fission product inventory escaped the building, although 5–10% of the material escaped the reactor vessel and remained within the building.

More representative of potential releases in large commercial LWRs was the TMI Unit 2 accident in Pennsylvania in 1979. As a partially mitigated LOCA that involved substantial core damage, TMI-2 was not the most severe type of accident postulated in reactor safety analyses, but it was one in which significant radioactive releases could be expected under current regulatory source term assumptions. The actual release of radioiodine to the atmosphere was very small—only about 18 curies out of 22 million curies of iodine that were released from the fuel. Almost all the iodine was retained in the reactor's primary cooling system, containment building, and auxiliary building. A much larger quantity of the noble gases xenon and krypton was released (about 10 million curies, or about 2% of initial noble gas inventory in the core), but because of the short half-life of these elements, most of the xenon and krypton decayed to nonradioactive forms before they escaped from the plant.

Radiation levels outside the TMI-2 site were quite low; estimated doses to the public were also low, ranging from an average of about 1 millirem (less than the annual dose from watching a color television) to a maximum of about 70 millirem for a small number of people.

It is important to note that there was no failure of the reactor containment building at TMI-2, and the radiation releases that did occur were through leaks in the secondary systems of the auxiliary building. Even if the containment building had failed (a highly improbable event), it has been estimated that the amount of iodine measured inside the containment atmosphere, had it been released to the environment, would have produced radiation doses insufficient to cause even one immediate fatality. In contrast, the current technical basis for regulatory risk estimates suggests that thousands of people would die in a TMI-type accident.

Source term factors

If reactor core fission products are released from the fuel under severe accident conditions, a multitude of physical and chemical factors determine the extent to which the products travel through the reactor primary cooling system, the containment building, and auxiliary systems to the outside environment. These factors were not well understood quantitatively, however, when current source term estimates were originally made, so high values were deliberately chosen as a conservatism to account for the uncertainty.

WHAT IS SOURCE TERM?

Source term refers to the type, quantity, and timing of release of radioactive fission products that reach the outside environment in a nuclear power plant accident. Fission product elements—krypton, strontium, iodine, xenon, cesium, and tellurium—are fragments of the uranium atoms that divide during the fission reaction. Radiation from these elements is the spontaneous emission of particles from the nuclei of atoms—a process known as radioactive decay.

Among several source term factors that influence how dangerous a particular material would be in an accidental release, radioactive decay is the most basic consideration. The radioactivity of a substance, expressed in curies per gram, is reflected in its half-life, or the time required for half of a quantity to decay to a nonradioactive form. Elements with long half-lives require more material to produce a curie of radiation than elements with short half-lives. This means specific activity is generally more important in considering radiation hazard than the amount of material present. For example, spent reactor fuel contains much unfissioned uranium, but uranium's specific activity is very low compared with that of iodine, which exists in relatively small amounts but has a high specific activity. Iodine is therefore of more concern as a hazard.

The chemical form of a fission product element is also a key factor in judging its hazard. If released from fuel in elemental, gaseous form, a chemical may be more likely to migrate through the reactor's internal systems than if released as a compound with another element.

The type of radiation given off by a radioisotope is another factor that determines the near-term health hazard of a fission product release. Alpha and beta particles are of less concern than the more penetrating and biologically damaging gamma rays. Iodine and cesium, both of which are emitters of beta particles and gamma rays, are of particular concern in human health effects.

Another factor related to the health hazards of fission product release, but technically beyond the scope of source term research, involves the interaction of specific fission product elements with individual biological systems. Inert gases, such as xenon and krypton, are not well retained in the human body and are thus of less concern than iodine, which concentrates in the thyroid gland. □

period / group	Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII	VIII	VIII	Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0
1	1 H hydrogen																1 H hydrogen	2 He helium
2	3 Li lithium	4 Be beryllium											5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
3	11 Na sodium	12 Mg magnesium											13 Al aluminum	14 Si silicon	15 P phosphorous	16 S sulfur	17 Cl chlorine	18 Ar argon
4	19 K potassium	20 Ca calcium	21 Sc scandium	22 Ti titanium	23 V vanadium	24 Cr chromium	25 Mn manganese	26 Fe iron	27 Co cobalt	28 Ni nickel	29 Cu copper	30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	35 Br bromine	36 Kr krypton
5	37 Rb rubidium	38 Sr strontium	39 Y yttrium	40 Zr zirconium	41 Nb niobium	42 Mo molybdenum	43 Tc technetium	44 Ru ruthenium	45 Rh rhodium	46 Pd palladium	47 Ag silver	48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon
6	55 Cs cesium	56 Ba barium	57 La lanthanum *	72 Hf hafnium	73 Ta tantalum	74 W tungsten	75 Re rhenium	76 Os osmium	77 Ir iridium	78 Pt platinum	79 Au gold	80 Hg mercury	81 Tl thallium	82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
7	87 Fr francium	88 Ra radium	89 Ac actinium **	104 *Rf* *rutherfordium*	105 *Ha* *hahnium*													

* 6	58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb terbium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tm thulium	70 Yb ytterbium	71 Lu lutetium
** 7	90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

I N T E R N A T I O N A L   S O

Research Focus	Changes during fuel degradation	Fission product release from fuel	Aerosol behavior in primary system
Project Sponsor	U.S. Nuclear Regulatory Commission—Oak Ridge National Laboratory Federal Republic of Germany United Kingdom	NRC—Power Burst Facility EPRI—Argonne National Laboratory International Collaboration: LOFT* France United Kingdom	NRC—ORNL International Collaboration: Marviken test reactor** EPRI—Argonne National Laboratory

Until recently there was no attempt to identify the magnitude of overprediction in source term values because such studies as WASH-1400 showed that the risk of severe reactor accidents was exceedingly small compared with other industrial accident risks, even with overestimated source terms. Although the TMI accident conformed to WASH-1400's risk estimates, the accident caused concern that the probability of such a severe accident was not as low as had been calculated. In the last few years this has given rise to a major R&D effort to obtain a detailed understanding of specific fission product species that are released when reactor fuel is overheated or melted.

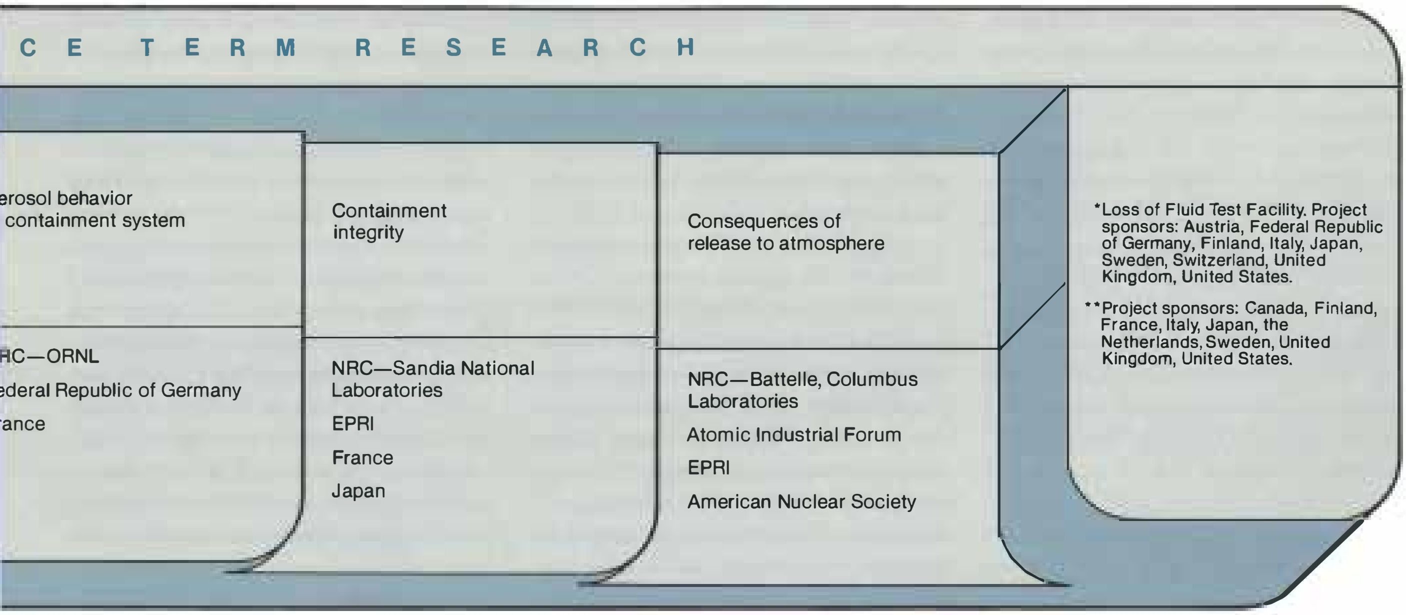
There are half a dozen isotopes of iodine in typical LWR fuel; iodine-131 is the most abundant of these. Likewise, there are numerous species of cesium and strontium isotopes and of many other radioactive elements. But the precise physical and chemical forms of these species as they are present in the fuel, particularly under core-melting conditions, make an important difference as to how these species dissociate from the other fuel components and are transported away from the reactor vessel.

For example, the current regulatory source term includes the assumption that elemental iodine (I_2), a gas, is the predominant chemical form of radioiodine released during fuel melting. This assumption goes far to explain why the calculated consequences of a core-melting accident are so high. As a gas, iodine is readily dispersed in the open atmosphere and could be inhaled by humans standing in the path of the radioactive plume. Iodine concentrates in the thyroid, where large doses can produce nodules that can become cancerous in a small fraction of the cases.

It is now generally accepted, however, that the predominant form of iodine released is not a gas but a salt, formed in combination with another fission product isotope, cesium. Cesium iodide, like common salt, dissolves easily in water and remains there unless rather special pains are taken to separate it out. Elemental iodine, on the other hand, is volatile, meaning that if it existed it would vaporize at relatively low temperature from the host medium—in this case, reactor fuel pellets.

Because most of the iodine is released as cesium iodide, much of it is likely to be taken up in the primary cooling system water. This partly explains why a very small amount of iodine was detected outside the TMI-2 plant, although a substantial quantity was released from the fuel. The president's commission appointed to probe the TMI accident concluded that of the roughly 22 million curies of iodine released from the TMI fuel, 7.5 million curies were retained in the primary coolant loop, 10.6 million were contained in the reactor's cooling water trapped in the containment building, and about 36 thousand curies were held in the containment atmosphere. Some 4 million curies of iodine reached the auxiliary building tanks, the source of the 18 curies that escaped to the environment.

Aside from isotope species solubility, there are many other mechanisms that can attenuate the movement of fission products released from the fuel before they can reach the outside. Such mechanisms include the coagulation of fission product aerosols (mist or dust containing large and small particles of fuel and fis-



sion products) both in the primary cooling system and in the containment building; plate-out of fission products on the walls of the primary cooling system and the condensation of fission products in the cooler regions of the cooling system; and the reaction of fission products with condensing water in the containment building and the auxiliary building.

These mechanisms are widely acknowledged to exist and to be operating to some extent in any fission product release, but precisely how they operate and their combined effect in attenuating the release and transport of fission products are not sufficiently known to the degree of detail required to satisfy those responsible for reactor safety regulation.

The timing of fission product release from the core is another important factor. Some of the analysis currently used in source term estimation postulates an essentially instantaneous progression from fuel melting to largely unrestricted release to the environment. Prior to release, however, failure of the reactor pressure vessel and the reinforced concrete containment structure would have to occur. But by allowing chemical reactions and condensation to reduce the amount of fission products available in the containment for environmental release, the length of time between core release and containment failure could have a major influence on the amount of core material ultimately released. Moreover, the slower the accident progression, the more the radioactive core inventory decays, further reducing the potential source term.

Under current risk assessment of a maximum credible accident, the containment building itself (a massive barrier engineered to prevent fission product release to the environment) is assumed to undergo gross structural failure as a result of overpressurization from the buildup of steam and other gases or a pressure pulse from steam spikes or hydrogen burns. It is much more probable, however, that it would take hours from the start of fuel melting before the point was reached that the containment building might be in danger of being breached because of overpressurization. Recent work at the Kernforschungszentrum Karlsruhe (KFK) in West Germany indicates that for German containment designs, gross failure caused by overpressurization would take at least four days to occur.

The research task

As the preceding discussion implies, more realistic estimates of reactor accident consequences require experimental research on a broad front in order to close gaps in the existing source term data base. The challenge for the many government, industry, and international research groups engaged in source term research is to gain a consensus from a broad spectrum of scientific disciplines on the precise details of the physical processes involved in core melting, as well as in the many potential accident scenarios that could lead to core melting.

The array of source term research projects around the world breaks down into two broad categories: separate, specific laboratory-scale tests of the effects of melting and other variables on fission product formation and the reaction of fission products with other substances, such as metal or water; and large-scale integral experiments to study the behavior of fission products as they are transported through a reactor's internal systems under realistic accident conditions. Data from the integral experiments are used to validate the predictive analytic methods developed from the laboratory-scale work to derive improved models of the physical and chemical processes—models that, in turn, yield more realistic source term estimates.

To better understand the physical and chemical mechanisms of fuel melting, studies in the United States under EPRI and NRC sponsorship, as well as in Great Britain and West Germany, are focused on the reactions that can occur in fuel melting, the rates of those reactions, and their associated thermal effects. Of particular interest is the extent to which the uranium dioxide fuel is exposed to steam and hydrogen and how this influences the rate of fission product release and the physical conditions of the core.

Laboratory and integral test reactor experiments are under way to study the actual release of fission products after overheating has ruptured the zirconium fuel cladding. The aim is a precise identification of fission product species, as well as the release rates and physical forms of the released material. Scientists at Oak Ridge National Laboratory, under NRC sponsorship, are looking at the volatilization rates of fission products and structural materials by heating kilogram quantities of irradiated fuel. Another approach, sponsored jointly by EPRI and DOE at Argonne National Laboratory, involves induction heating of spent fuel rods for examination with special equipment that can identify the chemical species of the fission products. A somewhat different technique is being similarly applied at the KFK nuclear research center. Great Britain is also conducting laboratory work in this area.

Test reactor programs to study fission product release involve integral experiments that simulate the time and temperature history of specific accident scenarios. Although this type of research is more expensive to conduct than laboratory-scale tests, in-pile experiments are important in order to more accurately define the technical parameters of fission product release. U.S. in-reactor experiments are being performed in Idaho at the power burst facility under NRC sponsorship and at Argonne's TREAT facility with support from EPRI. France also has an in-reactor program.

An internationally sponsored series of experiments is getting under way at the Marviken power plant in Sweden to study the transport of fission product aerosols in the primary cooling system. Organizations from nine countries, including NRC and EPRI from the United States, are supporting the Marviken experiments, which are approximately full-scale. The tests, to be performed by Studsvik Energiteknik Ab, will be conducted in a decommissioned reactor. The $8.5 million program, expected to continue into 1985, is the first large-scale simulation of fission product transport through a reactor's internal systems. High-concentration aerosols, with densities exceeding 100 gm/m^3, will be studied under simulated accident scenarios.

To support its participation in the Marviken program, EPRI is sponsoring, on its own behalf, smaller-scale aerosol experiments; these will look at aerosol interactions in various reactor components and in small test loops to better understand the scaling phenomena of aerosol processes.

A distinct set of issues must be considered if one assumes that fission products released from the fuel leak out of the primary cooling system and into the containment building. One aspect of the containment structure's role in determining the accident source term relates to the behavior of fuel and fission product aerosols as they are released into the containment. West Germany is conducting studies of aerosol movement in containment at Battelle Memorial Institute in Frankfurt, and NRC is sponsoring work at Oak Ridge as well.

Another issue involves the ability of safety-related equipment in the containment to continue functioning in a high-radiation environment. EPRI is already sponsoring research on containment equipment qualification, and research results from source term work will be incorporated as data become available.

The length of time required for a containment structure to fail as a result of overpressurization and the manner in which it would fail are subjects of extensive investigation; current estimates of the margin of overdesign of containment for safety range from 1.5 to 2.5. WASH-1400 assumed early catastrophic failure of the containment in a severe accident and very little attenuation of fission product release as a result. EPRI is investigating both the potential internal containment loading from overpressurization and the mechanisms by which the structure could fail. EPRI's Nuclear Safety Analysis Center (NSAC) has recently completed a comprehensive set of experiments, and large-scale follow-on tests are planned on the formation, combustion, and management of hydrogen in the containment. The work indicates that the effects of hydrogen combustion can be significantly curtailed by the use of ignitors and water sprays. Data from these and other experiments are being used to estimate the pressure loading on containment structures.

Other EPRI research may show that slow leakage and not catastrophic failure would actually occur from containment overpressurization. Tensile tests to measure the cracking and leakage through containment walls are being sponsored by EPRI at Skokie, Illinois, where the Portland Cement Association has constructed a special facility to apply the tremendous loads required to crack 4-ft-thick (1.2-m) concrete panels. This work will complement overpressurization experiments on scale-model containment buildings being performed by Sandia National Laboratories under NRC sponsorship.

Other EPRI-sponsored experiments are under way at Argonne National Laboratory to study the formation of debris in a postulated pressure vessel melt-through followed by the spilling of molten fuel onto the containment floor. In addition, computer codes used to predict containment performance are being substantially upgraded.

Other extensive testing and analysis of containment structural integrity under thermal and pressure loading is being conducted in Japan by the Central Research Institute for the Electric Power Industry (CRIEPI). France is performing containment structural tests under the direction of the Commissariat à l'Energie Atomique (CEA). In the United States, DOE has defined a comprehensive research plan on containment under degraded core conditions, which is contingent on congressional funding.

Reassessment of risk

Aside from the diverse scientific research aimed at a better understanding of fuel melting and the mechanisms of fission product release, EPRI and other groups are reevaluating risk assessment analyses at individual nuclear plants to determine the magnitude of reduced severe accident consequences implied by more realistic source term values. EPRI is reevaluating the consequences of the important accident scenarios for the Surry reactor, one of two plants used as case studies in WASH-1400. Results produced by the probabilistic risk assessment methodology, using new source term data, will be compared with those from WASH-1400 for the same reactor.

NRC is sponsoring similar reconsiderations at Battelle, Columbus Laboratories. In the Battelle work, four representative U.S. nuclear plants—Surry, Peach Bottom, Grand Gulf, and Sequoyah—are being evaluated under selected risk-dominant accident sequences, using improved methodology and modeling of key fission product release processes.

In addition to these efforts, other industry groups are engaged in reevaluations of accident consequences. The Atomic Industrial Forum's industry degraded core rulemaking (IDCOR) program is examining sequences in four plants, which include three of those that Battelle is studying (the Zion plant is being studied in place of Surry). A special committee of the American Nuclear Society is taking a slightly different approach to determine realistic severe accident source terms, focusing on an evaluation of fission product release and transport steps in various accident scenarios.

Integrating the results

Perhaps the most challenging aspect of source term research is in achieving closure and integration of the many experimental programs going on around the world. Ultimately, the research will lead to regulatory source term values that more realistically reflect the potential consequences and risks to the public of a severe nuclear plant accident. But the translation of laboratory and test reactor data into new regulatory standards will continue to require the cooperative approach of government, industry, and the R&D community that has marked the overall source term research effort.

An indication that the source term work is being taken seriously by NRC was that agency's establishment in late 1982 of the Accident Source Term Program Office to coordinate both the technical assessments of fission product release and the integration of those assessments into the regulatory framework. Moreover, NRC has issued a tentative schedule for the timely incorporation of research results into policy development and reactor licensing. The schedule suggests that new interim source term values may be published this year, and NRC staff recommendations for revised final source terms may be issued within a year later.

As the focus on source term turns to the arena of standards and rulemaking, EPRI is helping to integrate the research results based on its extensive participation in and management of much of the technical work. Soon, more realistic source term values could be in place that will provide more meaningful estimates of reactor accident consequences for planning and licensing purposes. The goal is one to which all parties agree: a clearer perception of the real risks from reactor accidents and enhanced safety of nuclear power plants.

Further reading

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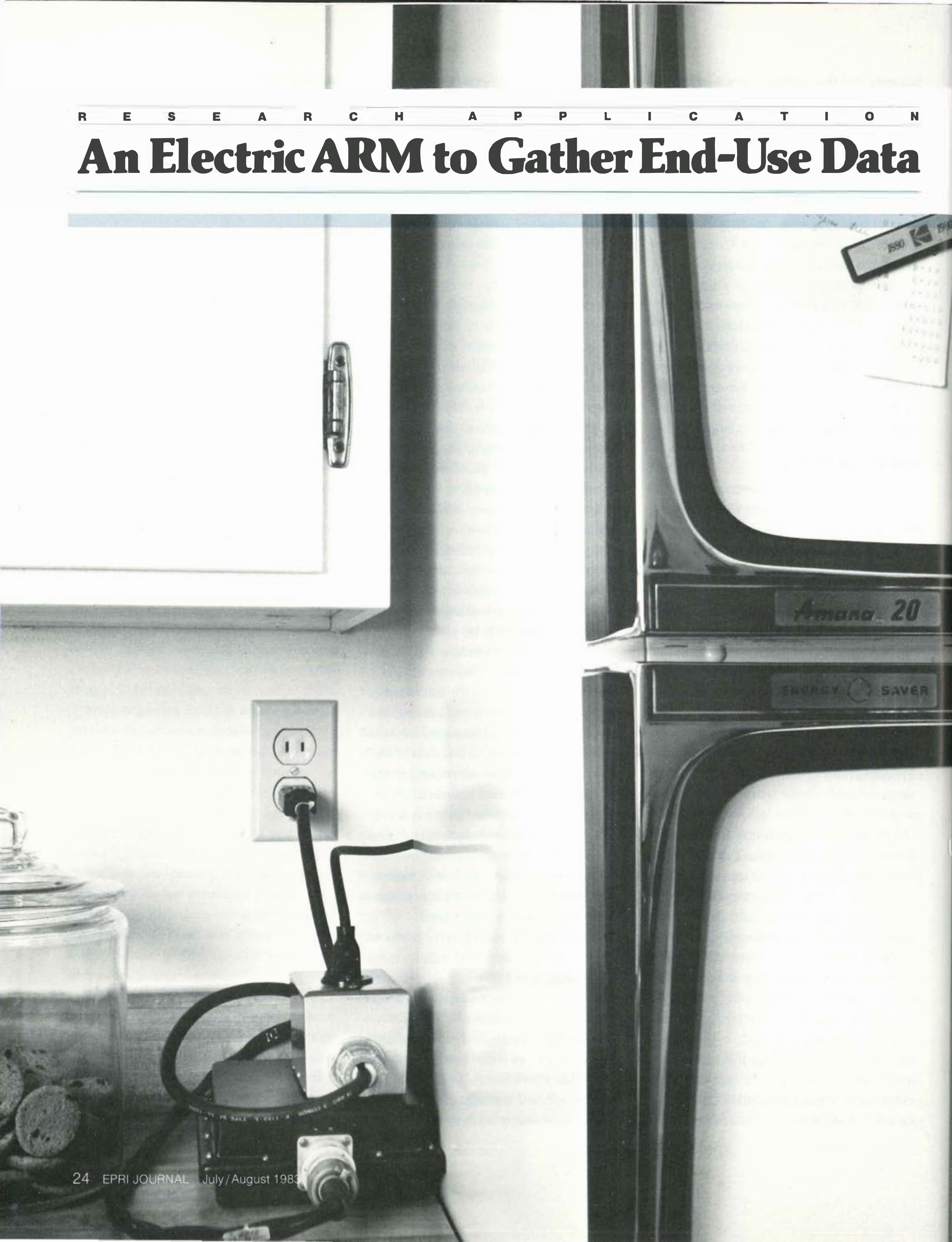
This article was written by Taylor Moore. Technical background information was provided by F. J. Rahn and Richard Vogel, Nuclear Power Division.

RESEARCH APPLICATION

An Electric ARM to Gather End-Use Data



Until recently, if a utility wanted to collect information on how much electricity a customer's refrigerator used, or how many hours a washing machine ran, or what hours a portable heater was operated, there was only one way to get the information—the utility had to rewire the customer's home, appliance by appliance, directly connecting each load to a special meter. The rewiring was expensive for utilities and inconvenient for customers. Not surprisingly, most end-use electricity studies were limited to simple surveys of total household electricity use rather than appliance-specific use.

Success story

Now there's a better way to collect the detailed end-use load information that utilities need to prepare more-accurate load forecasts and to develop effective conservation and load management programs. The electric appliance research metering (ARM) system, developed by EPRI and Robinton Products, Inc., of Sunnyvale, California, is easy to install, less expensive than rewiring, and much more acceptable to utility customers. The Electric ARM, four years in the developing, is now being manufactured by Robinton, and EPRI is applying for a patent on the system. ARM has been on the market for one year now and has already rung up almost a million dollars in sales to at least eight utilities; more inquiries are coming in daily.

The electric appliance research metering (ARM) system enables utilities to collect detailed end-use load information without costly, inconvenient rewiring.

The Electric ARM sidesteps rewiring by using existing household electric wiring to carry coded information on appliance electricity use to a special receiver outside the house. All the utility has to do is plug any appliance into one of the system's small solid-state meter-transponders, boxes about the size of ordinary electric timers, which are then plugged into conventional electric outlets. The devices periodically measure electricity use and send signals coded with watthour information to the receiver. The receiver interprets the coded signals and transmits pulses to a recorder, which is usually located next to the receiver.

The sophisticated digital code that distinguishes the output of one transponder from the output of another permits easy identification of individual appliances. Because the system accommodates eight meter-transponders, information can be gathered simultaneously on up to eight different appliances. These appliance-specific data are extremely useful to utilities in preparing load forecasts and evaluating such approaches as load management. For example, a typical customer has some flexibility in deciding when to use a dryer but not in deciding when a refrigerator will operate. Detailed readings on appliance use will help utilities identify what and how much load is deferrable.

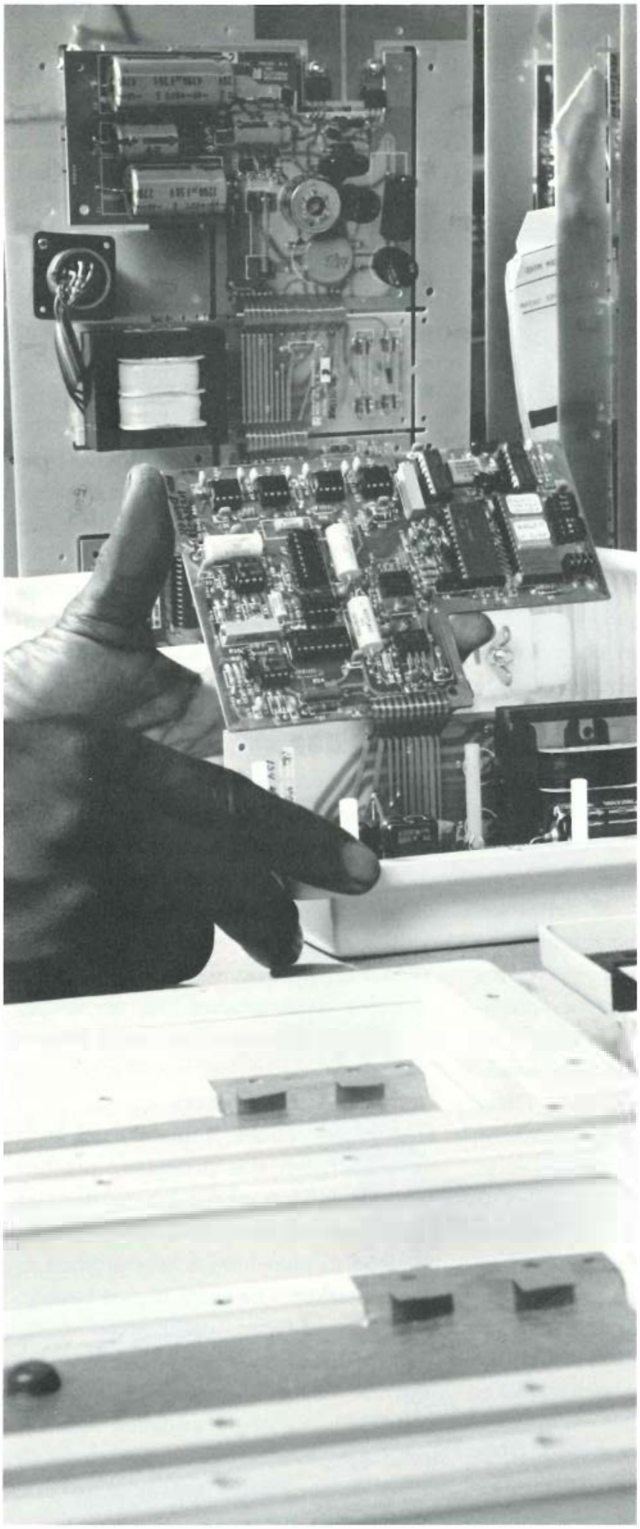
When the utility has gathered sufficient data at one household, the Electric ARM can be packed up and moved to another location. A typical ARM installation costs about $2000—roughly the same cost as rewiring a house—but most of ARM's cost is for reusable equipment, rather than for the labor required to rewire.

Robinton's largest order for the Electric ARM so far is from Pacific Power & Light Co. (PP&L), which recently installed ARM systems in 60 Oregon homes to collect load data. Detroit Edison Co., Georgia Power Co., Long Island Lighting Co., Mississippi Power Co., Niagara Mohawk Power Corp., Salt River Project, and Wisconsin Public Service Corp. have also placed orders with Robinton, and several other utilities are negotiating orders as well.

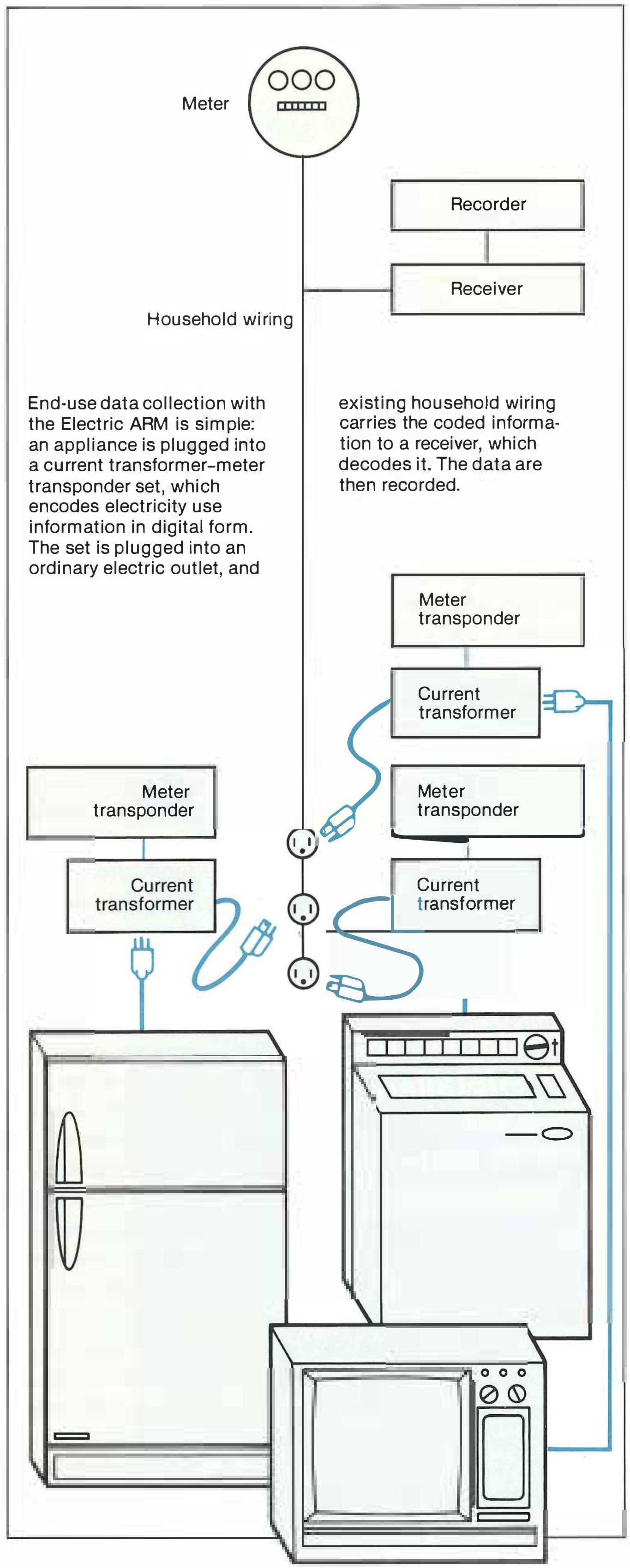
The Electric ARM has passed independent laboratory tests with flying colors; in fact, allows Robinton President Lev Dawson, "The meter's accuracy has far exceeded our expectations." And utilities quickly appreciate ARM's other advantages. For example, PP&L could conduct only limited end-use surveys before the advent of the Electric ARM because rewiring was so expensive and it was difficult to secure customer permission. "But after showing customers the Electric ARM and explaining what it involved, our field people had very little trouble with people refusing permission," reports Nancy Esteb, PP&L analyst. All ARM's advantages considered, "We're now able to do studies that we simply wouldn't have done before," says Esteb.

Touch and go

The Electric ARM is plainly off to a good start, but this promising product almost didn't get off the ground because of the research and manufacturing risks involved in launching a new product in a new market. The story begins back in 1978. Edward Beardsworth, project manager in the Demand and Conservation Program, Energy Analysis and Environment Division, was dissatisfied with the techniques available for collecting end-use data. They were too expensive and too troublesome. In one project, for example, EPRI rewired 10 homes in each of 12 utility service areas with conventional information-gathering equipment; yet even with only 120 homes, the rewiring



The Electric ARM is now being manufactured by Robinton Products, Inc., the Sunnyvale, California, firm that cosponsored the ARM project with EPRI. Sales of nearly a million dollars have already been made to at least eight utilities, which use the systems to gather information for load forecasts and conservation and load management programs.



End-use data collection with the Electric ARM is simple: an appliance is plugged into a current transformer–meter transponder set, which encodes electricity use information in digital form. The set is plugged into an ordinary electric outlet, and existing household wiring carries the coded information to a receiver, which decodes it. The data are then recorded.

proved discouragingly expensive, and EPRI encountered numerous problems with equipment installation, maintenance, and lost data. There was also the problem of sample integrity. Utilities conducting end-use surveys with conventional techniques found that carefully selected scientific samples became distorted when many targeted customers declined to participate in surveys because of the potential inconvenience.

Beardsworth was certain that rewiring could be avoided by transmitting load data over existing household wiring. He was also sure that off-the-shelf equipment could be engineered to answer the purpose. Yet he was uncertain as to who would be willing to join EPRI in developing the product and bringing it to market. "The Electric ARM is a specialty product," explains Beardsworth. "It's of interest to utilities in quantities of hundreds—dare we say thousands? But certainly not in the millions." A product with such a limited market would be unappealing to many manufacturers looking for big sales.

Then Pacific Gas and Electric Co. referred Beardsworth to Robinton, a new firm in California's so-called Silicon Valley of high-technology companies. Robinton had recently gone into the business of developing and manufacturing microprocessor-based utility industry equipment, such as solid-state pulse-recorders and load management equipment, and it sounded as if it might be a good candidate to develop the Electric ARM. Beardsworth got in touch with the firm and talked over what EPRI had in mind—the Institute wanted the Electric ARM developed by a firm that was also willing and able to manufacture the finished product for the utility industry.

Robinton Products was intrigued by the Electric ARM. It sounded like a perfect complement of the firm's line of utility products, and through the Electric ARM, Robinton could gain additional experience in the field of power line carriers. Even if the ARM would have a relatively small market, Robinton's other products were also geared toward the same electric utility market.

Still, Robinton had reservations about whether it would be able to recover its investment in developing, producing, and marketing the product. As Dawson explains, "Whether utilities are buying a power plant or a magnetic tape recorder, they are a conservative and unpredictable market. A product like the Electric ARM would attract the innovative utilities and the utilities that needed it to comply with PUC requests for more load information. But after those first sales you'd get the rest of the utility industry watching, thinking, 'I'll wait and see how it does.'" The waiting period could be years; PUC requirements could even change. The result could be that fewer of the systems would be ordered. Even with EPRI sharing the cost of R&D, the Electric ARM was a risky proposition.

Happily, an agreement was struck that reduced the manufacturer's investment risk in the Electric ARM to the point where Robinton considered the project viable. Over the course of the project EPRI provided $360,000 in R&D funding, to which Robinton added $228,000, bringing the R&D budget to a total of $588,000. Robinton ultimately invested almost $1 million in the project—a figure that includes production and marketing costs as well as its share of R&D, but the early funding by EPRI helped mitigate the manufacturer's risks enough so that Robinton was willing to give the Electric ARM a try. Robinton was also persuaded by EPRI's reputation for credibility within the utility industry—if the Electric ARM worked well, EPRI's endorsement would go far in marketing it. After careful deliberation, Robinton decided to take a chance on ARM.

Off and running

In mid 1979, EPRI and Robinton began their R&D on the Electric ARM. The project, completed by mid 1982, took a little longer than expected because the R&D team ran down one or two dead ends in its work on the new system. For example, one early concept was to use multiple channels of different frequencies to transmit data through the household wiring system—a technique called frequency multiplexing. In time, it became apparent that the approach would not work because the distorted power waveforms on the household wiring caused channels to overlap. Instead, the manufacturer chose to use only one carrier frequency for transmitting the data, assigning different digital codes for each transponder.

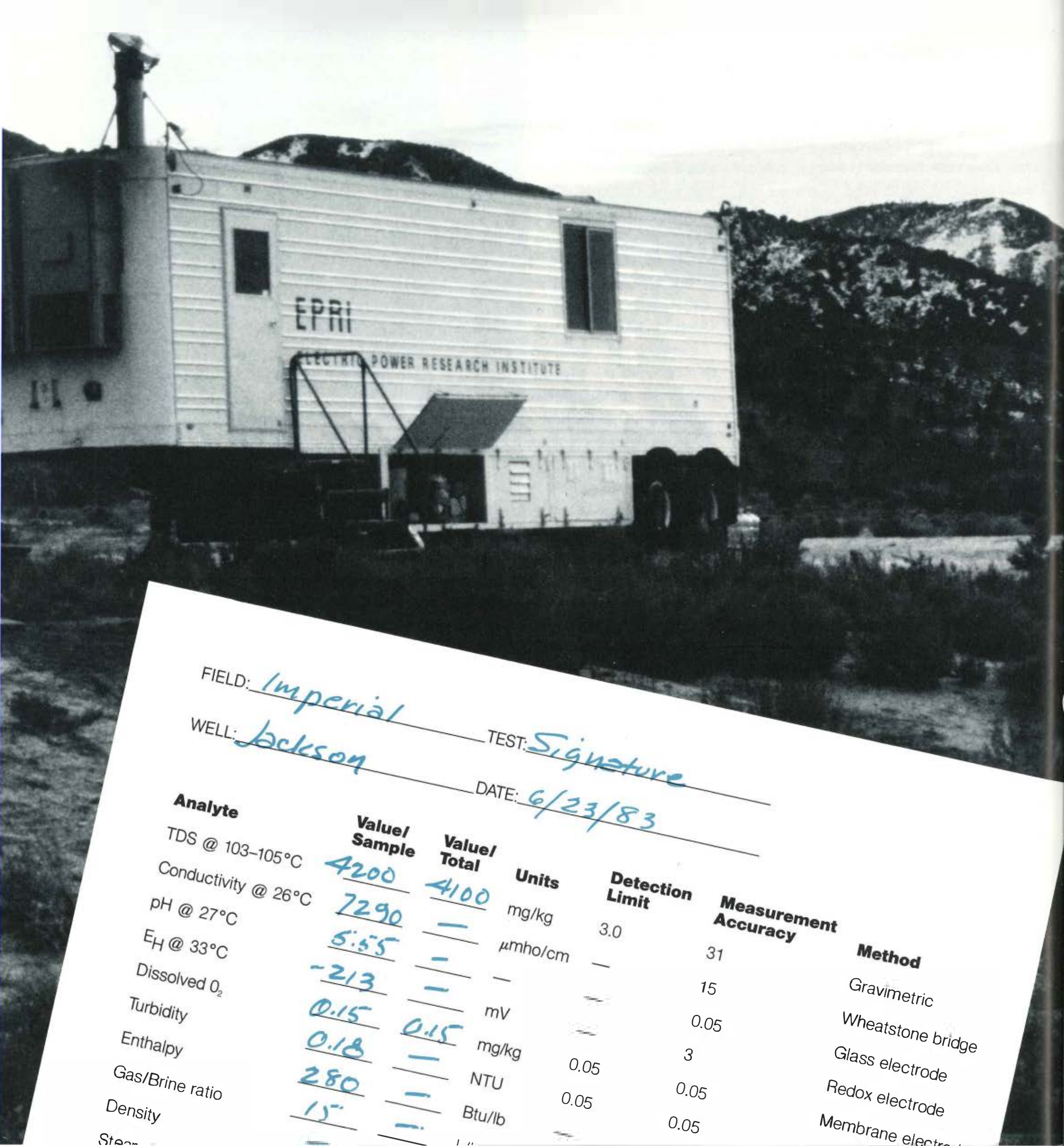
Another development was the decision to have the system measure not just current but actual power. Power, in terms of kilowatts, is the information that utilities need in their load research. Under ideal circumstances, power can be calculated by multiplying measured current by average line voltage. However, with non-unity and variable power factors, these calculated power estimates would not be as accurate as a direct measure of power. After starting out to design a system that measured current, EPRI and Robinton opted for the more accurate method of measuring power directly.

By the summer of 1982, the Electric ARM system was essentially completed, and in June 1982, the first order arrived from Detroit Edison Co.—Robinton was in business. Orders continued to come in and the firm anticipates more, thanks to a solid product, industry need, and EPRI's promotional efforts. The firm is even getting inquiries from smaller utilities whose interest in end-use metering had not been anticipated. According to Dawson, more than half of the ARM customers are doing load research that they would not otherwise have done were the new system not available. Utilities are evidently enthusiastic about ARM, but it took persistent cooperation between EPRI, Robinton, and utilities to make the Electric ARM a product, not just R&D. ■

This article was written by Nadine Lihach. Technical background information was provided by Edward Beardsworth, Energy Analysis and Environment Division.

Geothermal Analysis at the Wellhead

EPRI's mobile laboratory allows precise on-site chemical analyses of geothermal fluids to mitigate problems of corrosion and scale.



Geothermal water and steam contain minerals. It's as simple as that—or as complex. And therein lies one of the problems for those who want to extract a geothermal fluid from the earth and, in turn, extract energy from the fluid.

Minerals can deposit as scale (and can cause corrosion) in heat exchangers, pumps, valves, turbines, piping, and control instrument probes, not to mention in the well itself and even in the rock formation surrounding the bore. Scale control is a combination of measures to inhibit and remove scale.

Chemical additives and adjustment of thermodynamic conditions throughout the fluid loop of the power plant are ways to precipitate and remove minerals selectively before they can deposit. Chemical washes and abrasives are ways to remove scale; some washes can even be used (depending on the chemistry) while machinery is operating.

Scale can be dealt with in these ways only if the initial composition of the fluid is thoroughly known. The trick is to capture complete data ahead of time and use them to model the chemical changes that can be expected as energy is extracted from the geothermal fluid.

Sampling methods and equipment are important in the data acquisition. Chemical compounds and their form vary with the fluid temperature and pressure, so care must be taken not to disturb flow conditions at the sampling point and not to lose or contaminate constituents in the sampling process. Testing, analytic methods, and instruments are also important as a matter of precision and uniformity, as well as thoroughness.

But timeliness is especially important in the sampling process because the composition of a geothermal fluid can change markedly within hours, within minutes for some species. The circumstance calls for a fully equipped laboratory right at the geothermal wellhead.

For over three years now, EPRI and several of its member utilities in the western states have had exactly that.

On-site capability

EPRI's geothermal chemistry laboratory is compactly housed in a 40-ft (12-m) truck-trailer van. Designed, built, and operated under contract by Rockwell International Corp., the laboratory has been on ten assignments at eight sites in five states since its April 1980 shakedown tests at the East Mesa, California, geothermal test facility of the Department of Energy.

From November 1982 until late last spring, the laboratory was squared up on its jacks at Roosevelt Hot Springs near Milford, Utah. This is a hydrothermal site where Utah Power & Light Co. and EPRI are joined in the demonstration of a wellhead generating system and, in particular, a rotary separator–turbine that exploits the energy in both the liquid and vapor phases of the geothermal fluid.

By summer, the laboratory was scheduled to be at a hydrothermal test site in southern California's Imperial Valley. A new crystallizer flash vessel there is designed to preclude scaling by causing selected mineral species to be adsorbed on particles (either spontaneous precipitates or injected "seeds") as the brine vaporizes. The particles can then be removed from the flow stream.

Chemical measurements upstream and downstream from the EPRI-sponsored experimental power system components help to evaluate the performance of those components and provide insight for design improvements. But the Utah and the California assignments also involve characterizing the geothermal fluids coming from the wells—recording chemical signatures, as EPRI program staffers call it. Most important in the long run, these analyses are helping to build a data base on geothermal fluid chemistry and to solve problems caused by mineral scale.

Scale deposition from a given geothermal fluid results from a complex sequence of changes in pressure, temperature, fluid state, and flow conditions. Vasel Roberts, who has managed EPRI's geothermal energy systems R&D since 1975, explains. "As the water approaches the ground surface, the pressure in most systems becomes low enough for it to flash into steam. Mineral concentrations in the residual liquid quickly increase to supersaturation, forcing some species to precipitate."

By the time the fluid reaches the wellhead, it is a mixture of three phases: solid, liquid, and vapor; and the vapor, in turn, is a mixture of steam and noncondensable gases (typically carbon dioxide and traces of hydrogen sulfide). The stage is thus set for several more transitions as these fluids are separated, further flashed, and passed through valves, heat exchangers, turbine stages, condensers, and pumps before being returned underground via a reinjection well.

The sequence is complicated by the number of fluid constituents (over 400 possible species) and their concentrations. According to Roberts, "The total dissolved solids content can be as much as 350,000 parts per million—ten times that of seawater—and include 600 parts per million of silica alone. By contrast, the standard for silica content in utility boiler feedwater is only 0.02 part per million."

Even dry steam can carry troublesome species, Roberts points out. At The Geysers in northern California, volatile silica has been found to plate out in small amounts on the last rows of turbine blading, where the steam is approaching its exhaust levels of temperature and pressure. The silica is removed by sandblasting at regular service intervals; otherwise, it could upset the delicate dynamic balance of the turbine rotor, resulting in unwanted internal stresses.

Shortage of data

The genesis of EPRI's mobile chemistry laboratory was in 1976, although it was not recognized at the time. Roberts and his staff saw mathematical modeling as a way to trace fluid behavior and predict scale formation in geothermal wells and power systems. This was the principal early research effort.

Five computer codes for treating different aspects of geothermal energy conversion cycles were developed by Battelle, Pacific Northwest Laboratories. The geothermal fluid chemical signature at the wellhead is the fundamental input to these codes. For the most part, theoretical principles and empirical data govern the derivation of chemical equilibrium values elsewhere in the system at other temperatures and pressures. The equilibrium states are then used in modeling various kinds of scale deposition.

Data quickly became the point on which EPRI's research turned. Review of geothermal exploration and assessment literature yielded the disappointing conclusion that some 80% of the data were unusable for EPRI's purposes. Stated most broadly, the data were incomplete. Sampling conditions were not documented. Noncondensable gases had escaped from samples. Quality control of chemical analyses was inconsistent. And there were long lapses (more than transportation time alone) between sampling and analyses, during which the composition of stored fluids had changed.

In retrospect, these deficiencies are understandable. By and large, geothermal field and laboratory practices grew from the traditions of oil and gas exploration. Chemists simply sought indications of the presence and proximity of "heat"; scale formation in power components was outside the context of resource assessment as it was seen until quite recently.

In contrast, EPRI-sponsored researchers were preparing computer codes that would solve up to 300 simultaneous equations in the equilibrium analysis of geothermal fluids. To be useful in practice, the codes would need a data base of at least 8 gases, 200 aqueous species, and 187 solid mineral species—from 0°C to 300°C (32–572°F). James Jackson, EPRI's project manager for the mobile chemistry laboratory and its operation, makes the point that this extensive base is needed because many scaling reactions are subtle and indirect.

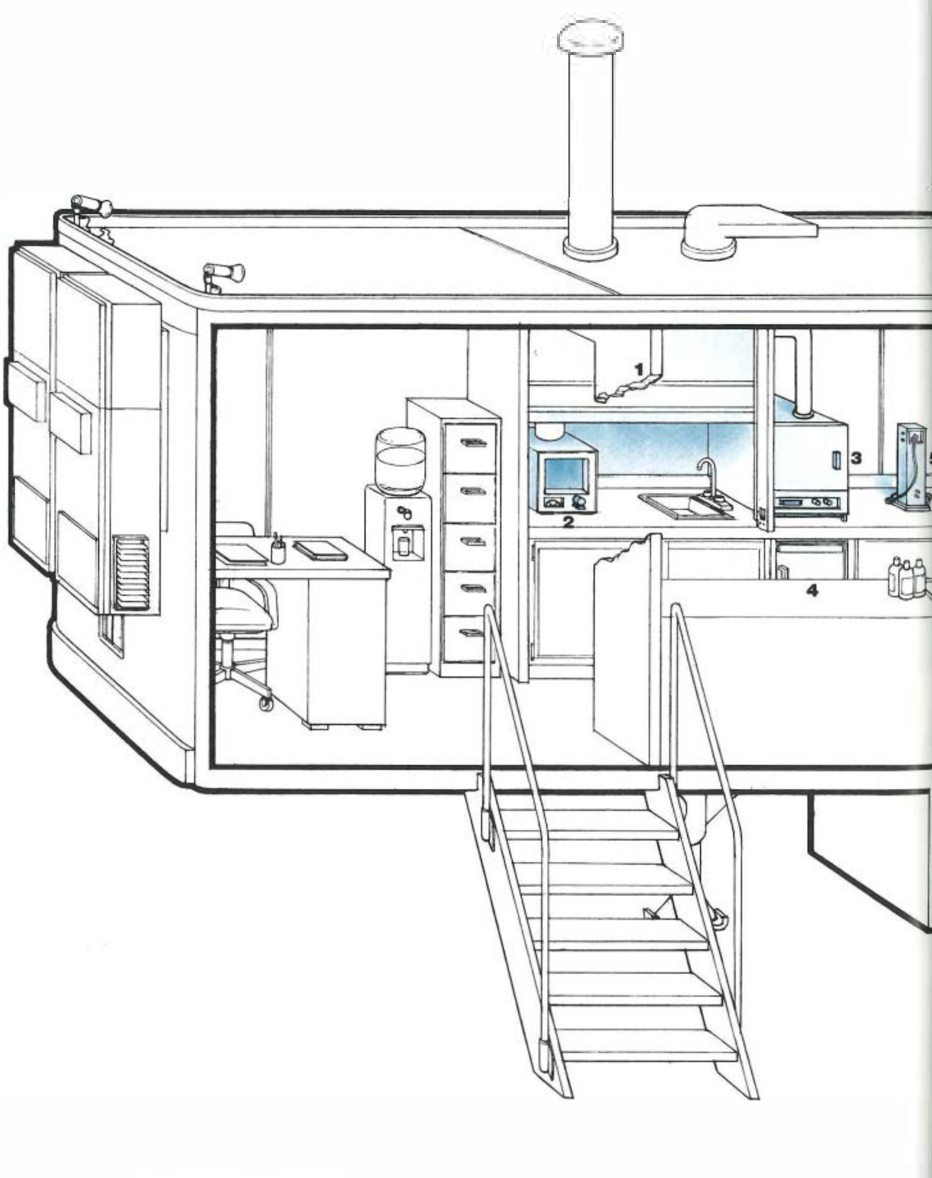
"We talk about hypersaline geothermal fluids," Jackson explains, "and we call them brine. They are indeed high in salt—mostly plain sodium chloride, also some potassium and calcium. These salts aren't scale problems themselves, but they influence the solubility of other species. Especially, they increase the solubility of species known to be bad actors, and those quickly produce scale when the brine is cooled or flashed for power production."

Instruments and analyses

After the concept of a mobile laboratory facility arose, a research project called for design and construction, and the contract for these tasks went to Rockwell. The same company (specifically, the Environmental Monitoring and Services Center of its Energy Systems Group) later agreed to staff and operate the laboratory under contract to EPRI.

A standard 40-ft (12-m) semitrailer bed became the planning module, its chassis modified with undercarriage bins to house gas cylinders, a compressor, and vacuum pump equipment. Air-ride shock absorbers were added to protect the laboratory and all its instruments on the road. Equipment and cabinets line the single fore-and-aft aisle of the insulated van body, with a small air-conditioned office at the forward end.

Two balances, an oven, turbidity and conductance meters, and a stereomicroscope are the instruments for measuring the physical properties of geothermal fluids. Those instruments are backed by others for chemical analysis: two spec-



trophotometers, a gas chromatograph, an automatic titrating system, and meters for pH, specific ion, dissolved oxygen, and chloride content.

Rockwell's Mary Jamin runs the laboratory. Together with one or two other chemists and a field technician, she conducts most of the analyses required for EPRI's research programs and the field tests of member utilities. Jamin's work is thus an intermittent commute between field sites and the Rockwell offices near Los Angeles.

Of themselves, the laboratory instruments and apparatus are not unique, and Jamin finds it difficult to select any single item for emphasis. "It's no more than what you'd expect anywhere—except out in the sagebrush!"

Analysis of noncondensable gases, however, can be singled out because those species are more than a source of scale. Carbon dioxide, the most common, reacts with moisture to produce an acid condensate that is corrosive. The same is true of hydrogen sulfide, the second most common. It and ammonia are also environmental pollutants if they occur in sufficient concentrations. And finally, all the noncondensable species are energy parasites—they take up space in the vapor passage, and extra energy must be expended to remove them.

At least seven such gases (carbon dioxide, oxygen, hydrogen, hydrogen sulfide, nitrogen, sulfur dioxide, and methane), as well as several hydrocarbons, can be measured with a gas chromatographic system carried in the mobile laboratory. This one analytic instrument symbolizes and dramatizes the high-tech capability that can now be parked beside any geothermal test site or producing facility.

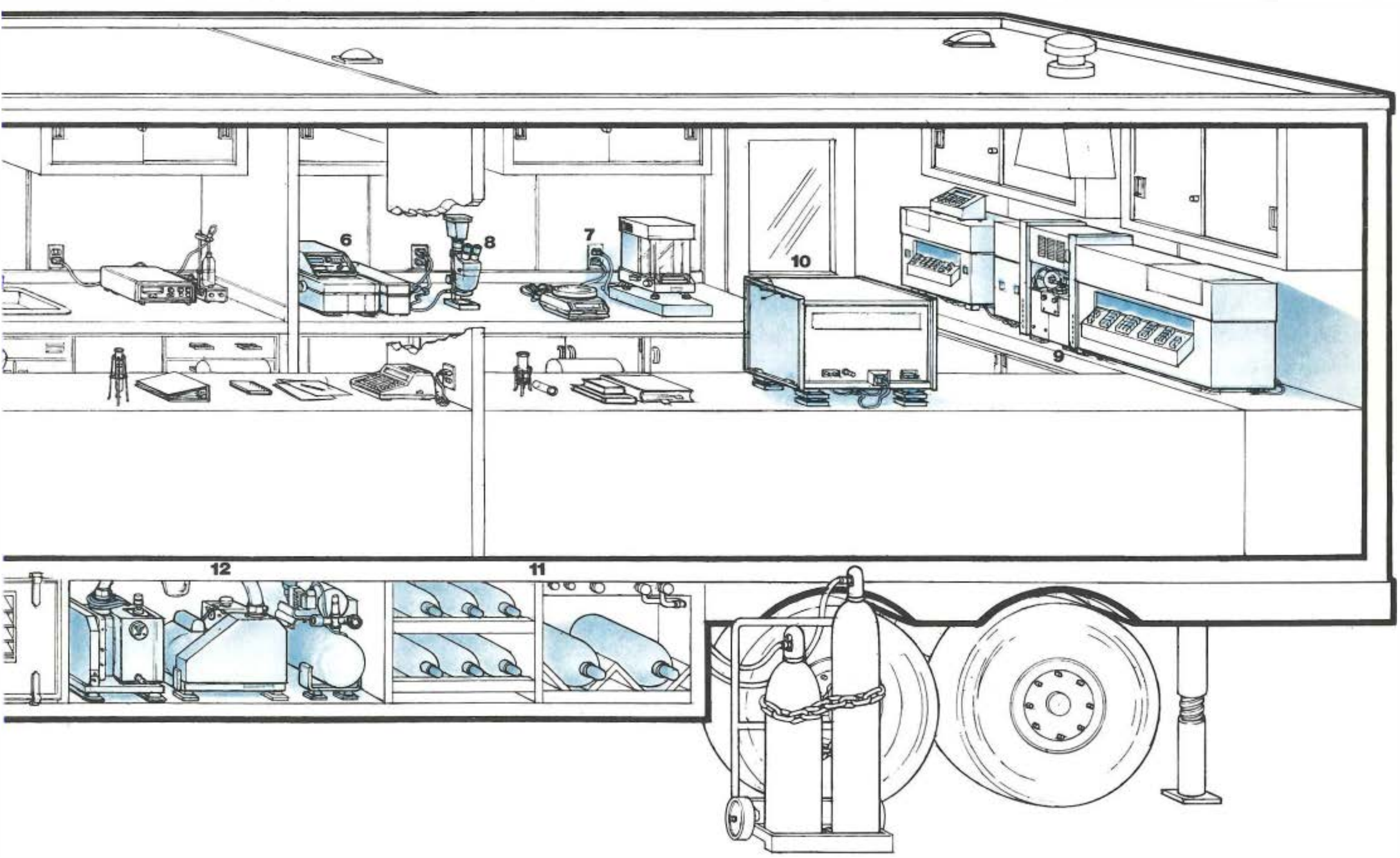
The essence of the chromatograph is its means for separating noncondensable species and for identifying and measuring them. It separates species by their different tendencies to be adsorbed in a column of granular material. It identifies them by the time needed for an inert gas to strip them loose, and it measures their concentrations by their thermal conductivities (all by comparison with records of known calibration samples).

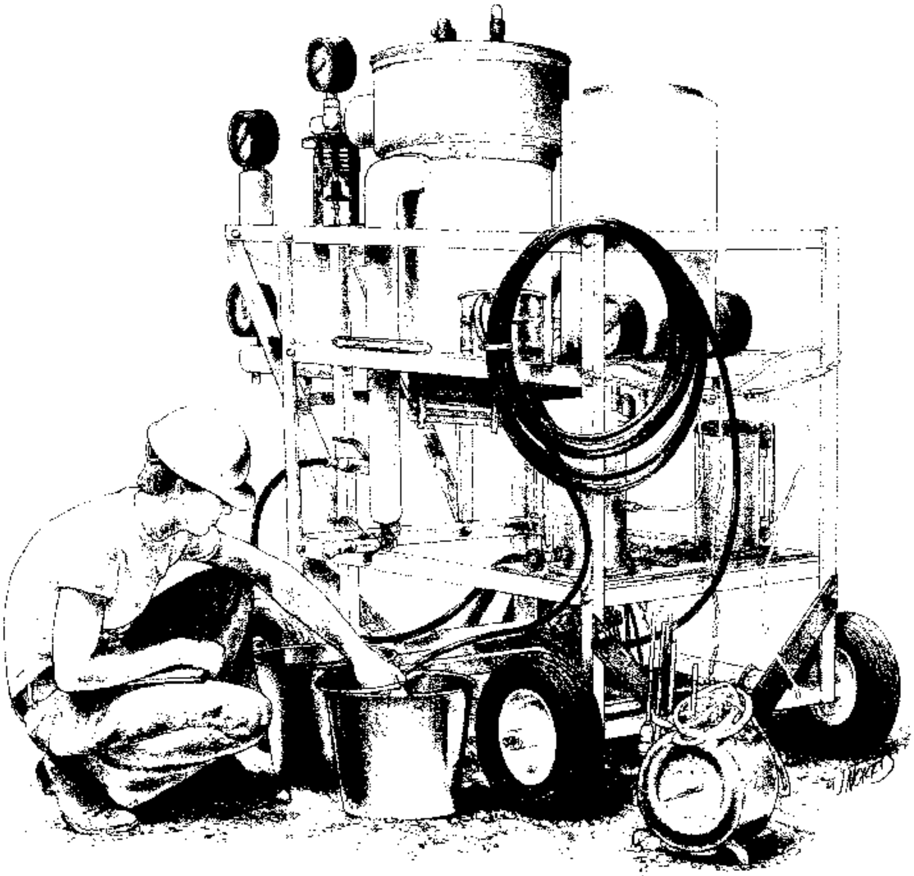
Uniform sampling methods

Together with the sophistication of the laboratory instrumentation, logical procedures for its use produce quality in the analytic results. Repetitive measure-

Careful layout of instruments and a planned sequence of standard procedures enable three or four chemists to work in the laboratory trailer at one time. A geothermal well signature analysis entails more than 50 analytic measurements and may require two to four weeks. More time is needed to monitor a well for possible changes in the geothermal reservoir or to test the performance of new power components under a range of flow conditions.

(1) Fume hood **(2)** Furnace **(3)** Drying oven **(4)** Refrigerator **(5)** Demineralizer **(6)** UV-visible spectrophotometer **(7)** Balances **(8)** Stereomicroscope **(9)** Atomic absorption spectrophotometer **(10)** Gas chromatographic system **(11)** Gas cylinders **(12)** Pumps and compressors





Flash separator and condenser vessels are key items used to collect geothermal fluid samples at the wellhead or at selected points in the fluid flow loop through a power unit. Standard procedures for use of this sampling system add precision to the results of chemical analyses.

ments and analyses of portions split from a single sample are among the techniques of statistical quality assurance used. Sample collection itself has been structured and routinized for a consistent start on all analyses.

This has been done in straightforward fashion by construction of a fluid sampling system, a three-wheeled cart that carries two insulated vessels, plus requisite valves, gages, and piping, which can be used alternatively as two condensers or as a flash separator and a condenser. The system can accept samples at pressures up to 500 psi (3.45 MPa). Its flexible stainless steel tubing and mating input connector can tap any valved sampling port at the wellhead or elsewhere in a geothermal power loop.

When fluid is valved directly to the ice-filled condenser, the aim is to drop the temperature and retain the condensate as a liquid sample for analysis. When fluid is first valved through the separator, the purpose is pressure drop and the retention of all possible gas species. A subsequent condensation step removes flashed steam from the vapor stream.

EPRI's Jackson underscores the significance of careful sampling and early analysis by recalling the accidental discovery of iron hydroxychloride before EPRI's mobile laboratory existed. It first showed up as an unexplained pattern during X-ray diffraction analysis of some mineral scale from piping at a geothermal site. The field chemist who had collected it was a pilot; on that occasion he happened to return immediately to the corporate laboratory. Also, as it turned out, he had sealed the sample in a jar.

The compound was finally identified and found to be very transient—it gives off hydrochloric acid gas and becomes iron hydroxide in a very short time if exposed to air. It is now known that iron hydroxychloride is a dominant component of scale in some hypersaline geothermal environments, but inadequate sampling procedures hid the fact for years.

Lab utilization grows

Three years of experience with the mobile geothermal laboratory has produced some evolution in its use—in both the conduct of analyses and their purpose. The initial demonstration at East Mesa was intended mainly to check the operability of all equipment after a 250-mile (400-km) trip and to test the fluid sampling system under field conditions. In addition, this demonstration led EPRI to formalize and structure the routine now used for sample collection and analyses.

Ensuing assignments have not only contributed to geothermal data base development (as originally seen, the principal use of the laboratory) but also, with the maturation of other EPRI geothermal R&D projects, to field tests of new hardware for energy conversion and scale control. The first two tasks of 1983 involve such tests: the rotary separator–turbine in Utah and the mineral crystallizer in California.

At some time the laboratory should become self-supporting, commercial in its own right, or the prototype for one or more similar units. For now, however, it is being used about 60% of the time—nearly 50% on EPRI programs and something over 10% on utility tasks. Heavier use, especially a greater share for utilities, can be expected in direct proportion to the pace of geothermal resource development for power generation.

This article was written by Ralph Whitaker. Technical background information was provided by Vasel Roberts and James Jackson, Advanced Power Systems Division.

Washington Hosts EPRI's Tenth Anniversary

A special program commemorating 10 years of collective research and development by the electric utility industry was held in Washington, D.C., on April 12. Excerpts from the four speeches, as well as remarks made by the program chairman, Chauncey Starr, are presented.

Proposed legislation 10 years ago in Washington, D.C., spurred the development of a research program to be conducted by the electric utility industry and resulted in the creation of EPRI. It was fitting, then, that utility and energy executives gathered in Washington to celebrate EPRI's tenth anniversary.

In his introduction, Chauncey Starr, EPRI's vice chairman and founding president, noted that EPRI's 10-year life makes it a relative newcomer in the hundred-year history of the electric utility industry. He emphasized that "research and development was a characteristic of the industry from its birth and has always been aggressively undertaken by both the individual operating utilities and their vendors, as evidenced by the historic increase in the past century in the economic efficiency with which electricity was delivered to consumers."

Although the idea for pooling the industry's resources to take on large research projects too costly for any one utility first surfaced over 30 years ago, it was, Starr noted, "the Northeast blackout of 1965 that led to a chain of events resulting in proposed legislation by Senators Magnusson and Hollings of the Senate Commerce Committee and put pressure on the utilities to create EPRI as a national R&D institution to serve them.

In spite of many reservations both inside and outside the utility industry, by January 1973, EPRI was in being on paper. I was elected president December 27, 1972, started January 1, 1973, and first met with the Board of Directors (all utility chief executives) on February 2."

Since that first Board meeting in February 1973, "EPRI has become an internationally recognized major participant in advancing utility technology, and the EPRI staff has established its credibility among the world's technical fraternities as an objective and knowledgeable source of information," Starr continued. "While the full value of R&D is difficult to quantify, the utilities' own estimates of the measurable savings from specific technical applications already in use indicate aggregate savings well in excess of EPRI's R&D costs. With the R&D pipeline just beginning, there is little doubt that the utility investment in EPRI is paying off in financial terms.

"EPRI's greatest contribution to the industry it serves," Starr remarked, "is the technical support it provides the utilities in meeting the nation's social objectives, whether they be abundant low-cost electricity, clean air, improvement of the environment, or public health and safety generally. The effective use of our natural resources to meet these social objectives cannot be accomplished by technological means alone, but technology does provide the range of options for doing so. Acknowledging my personal bias in evaluating EPRI, I feel a deep pride and

Starr

Culler

Dugan

Murrin

Gould

sense of accomplishment in EPRI's present and potential role in working with the utilities toward improving the public welfare."

EPRI's Mission

Starr then introduced Floyd Culler, president of EPRI since 1978 and the next speaker on the anniversary program. In outlining the coming decade of EPRI's R&D effort, Culler stated, "EPRI will develop new options to generate, transmit, and use electric power; improve the performance of existing equipment; conserve energy and manage loads; and develop simultaneously methods for the protection of the environment and the assurance of public health and safety."

Culler emphasized to the audience, "I think you are well aware of the potential for improvement in the economic efficiency of energy use in the commercial and residential sectors. The technology for these improvements is well established. We expect constant improvement in energy efficiency and, with it, an expansion in electricity use. Development will continue to enable energy consumption through load leveling and load management."

Central to energy R&D are questions pertaining to long-term resource availability. Culler commented on those that require continued attention, including the development of technologies to use coal, conventional nuclear power and breeder reactors, hydroelectric power, solar, wind, and geothermal power and, in the long-term, nuclear fusion.

"We will also continue the R&D necessary to rationalize nuclear power. Although the politics of disposal of high-level nuclear wastes has been partially resolved by the passage of the Nuclear Waste Disposal Act of 1982, demonstration has yet to be presented and accepted in the United States. There are still questions regarding the safety of nuclear power plants; we need a revision of nuclear power plant licensing procedures; and there are vexing questions about nuclear proliferation. Most of these problems can be solved during the next decade, but a very real effort, led by the electric industry, will have to be concentrated on their solution."

Commenting on the tangible accomplishments achieved over the past decade, Culler said, "EPRI has sponsored the establishment of a number of test centers: for overhead and underground power transmission; for mechanical transmission tower testing; for stack gas cleaning; for storage batteries; for the cleaning of coal; and for the nondestructive evaluation of nuclear plant hardware. I expect over the next decade we will see the establishment of additional test facilities."

In overview, Culler foresees that in the next decade "there will be a steady improvement in the economy and the financial health of the electric utilities. We will be better able to project future demand for energy and electricity. We will have arrived at a reasonable accommodation between environmental protection and economic development. We will have settled some of the nuclear licensing issues. We will have demonstrated a number of new technologies, such as gasification–combined-cycle power plants, fluidized-bed combustion systems, hydrothermal geothermal power plants, wind power plants, fuel cells, and large storage batteries. And as important, we will have made many small improvements to the availability and cost of conventional power systems. Basically, I am optimistic about the next decade. I think we can, and we will, solve many of the problems facing us."

Congressional Viewpoint

A congressional point of view on EPRI's first decade was presented next. Prepared by Marilyn Lloyd, representative from Tennessee and chairman of the Subcommittee on Energy Research and Production of the House Science and Technology Committee, the remarks were delivered by John V. Dugan, Jr., staff director for the subcommittee. "Certainly EPRI's 10-year track record in terms of sticking to a stable yet flexible utility R&D policy in the face of a vacillating federal policy is a proud accomplishment.

"From Chairman Lloyd's perspective, the driving force behind the swing of the federal R&D pendulum has been the ideological intransigence of both the present administration and its predecessor. Neither has proved to be a very desirable federal R&D partner from the standpoint of stability, understanding the need to share risk, and carrying out truly complementary technology development activity with the private sector. [Chairman Lloyd] does not believe that Congress is entirely blameless with regard to the stability of energy policy, but she does feel that a real desire to seek meaningful compromise and minimization of ideological posturing would have avoided much of the unproductive activity attendant to the energy policy debate of the last seven years."

In 1977 both Lloyd's committee and EPRI were confronted with the Carter administration's philosophy—"that dispersed technologies are inherently good, central station power plants are undesirable, and nuclear energy is an electrical option of last resort. This was clearly a mixed climate for electricity-related R&D to thrive, but coal and renewable R&D programs fared rather well, and even nuclear development survived frontal assaults by the administration and the environmental extremist camp."

Then in 1981, prospects of a new administration brought hope for a "more enlightened 'energy supply–oriented' R&D policy. As we well know, however, rosy prospects for a strong industry-government partnership in R&D were quickly dimmed when it became apparent that Mr. Stockman was to be the principal architect in deciding the nature and level of federal funding for energy research and development. The OMB director quickly terminated the demonstration projects for coal conversion in the Department of Energy, left the infant synfuels program to the U.S. Synthetic Fuels Corp., and savagely cut nonnuclear programs in such a way as to arouse the enmity of many moderate energy policy supporters against nuclear power.

"But," Lloyd stated, "even with these major policy swings, it is a credit to EPRI's leadership that it was able to rapidly redirect its programmatic funding to cover intermediate- and near-term programs that the Reagan administration drastically reduced over the past two years. It is reassuring to me that EPRI had the courage to testify frankly as to the need for a federal role in a variety of energy R&D programs—from fossil technology development to electric energy systems research.

"Yet," she continued, "it is a lamentable fact that this country has lost precious time required for technology development across the energy spectrum during the last six years. We still have not completed one near-prototype-scale technology demonstration plant in the breeder program or the synthetic fuels arena, and soft oil prices have blurred the national vision to the critical need for assured supply.

"In conclusion, it should be stated that EPRI has demonstrated institutional integrity and technical courage in terms of speaking out quietly but with clout against the policy extremes of the last two administrations; it has truly kept to the 'high ground.' We must continue to encourage the utilities to forge a strong, long-standing partnership with the federal government that is truly complementary in R&D from nuclear to clean coal burning. We can afford nothing less if we are to achieve our ultimate goal of assuring meaningful growth and an improved quality of life for future generations of Americans."

Productivity Challenge

The anniversary program's third speaker was Thomas J. Murrin, president, Energy and Advanced Technology Group, Westinghouse Electric Corp., who provided a perspective from the manufacturing sector. "Let me offer a challenge to EPRI and to the electric utility industry. Perhaps you can—and should—commit yourselves to the goal of attaining a 7% annual improvement in your productivity. EPRI is in an excellent position to help achieve such improved levels of performance.

"I believe in two convictions that are really one fact of American economic life: first, that American industry must insist on quality in every product it makes and every service it offers; and second, that America as a nation must accelerate its rate of productivity improvement, substantially and soon. It is my belief that greater quality and productivity are essential to America's economic future.

"The problem might be little more than academic—just a prolonged debate on free trade versus protectionism—if the proportions of the competition were not so awesome. The Japanese, for example, are substantially outspending us in such key production areas as robotics and flexible manufacturing systems.

"All this, of course, is vitally important to America's electric utility industry," Murrin emphasized. "You have prospered as energy suppliers to an innovative and growing American commercial and industrial system. When that system is in danger, you are in danger. When we try to formulate a response to such an international challenge, we begin with the realization that our answer must be an American answer—one which makes the most of our special strengths."

Murrin cited the quality of our industrial outputs as key to U.S. productivity problems. "We have learned a lot about quality in the process of making such changes at Westinghouse. Most of all, we have learned that quality is primarily a management task.

"Some pretty impressive results might be attained in the near-to-middle future if the electric utility industry were to make maximum use of high-tech capabilities, such as microcircuitry, electro-optics, fiber optics, and acoustics. There is no reason why utility systems should not be operated with such state-of-the-art instrumentation and control so that no machine need ever go to the point of failure."

Appealing to electric utility decision makers, Murrin suggested that they "reaffirm their commitment to technological advancement in such practical ways and support EPRI and other R&D sources not merely by their financial contributions but also by their timely application of the products of such work. I know that's not a new challenge, but it is indispensable."

Murrin cited EPRI as an excellent example of a national, unified approach. "Perhaps your greatest accomplishment over the past 10 years is your success in helping to unify an industry that has always been geographically, and often philosophically, fragmented. You have brought public and private power together in a common effort. You have welded the strengths of the total industry into one coordinated research and development program. Your productivity as an industry impacts every job that America does and every hope that America has."

A Question of Balance

The last speaker on the program was William R. Gould, chairman of the board and CEO of Southern California Edison Co. and immediate past chairman of the Board of EPRI. "It's a balance we're looking for here—balancing adequate supply on the one side with minimum cost on the other. Flexibility, diversification, and new technologies are key to arriving at the balance. And underlying it all is research."

Stressing the importance of electricity in providing a feeling of national well-being, Gould added that the industry is forced to deal with the challenge of ambiguity—accepting that ambiguity and incorporating it into planning. "This means formulating a flexible plan, remaining open to change, and becoming pro-active rather than merely reactive. That's the key to a healthy utility future.

"A flexible plan for Southern California Edison includes construction of small modular generation units with short lead times, fewer regulatory slowdowns, limited capital expenditures, and flexibility in fuel types. At Edison we now use nine primary energy sources to provide electricity to our customers—oil, natural gas, coal, water, nuclear, wind, biomass, geothermal, and solar. We're also participating with EPRI in the construction of the nation's largest integrated coal gasification project, and we're supporting fuel cell research as well."

Gould went on to say, "As long as we have a substantial dependence on foreign oil, we're out of control. Not only will future energy costs influence the domestic inflation rate and the price of goods and services but they will jeopardize the U.S. position in the world marketplace as well. Nations that have both cheaper labor and cheaper energy will be formidable competitors.

"One of the most fundamental lessons of the past decade is that energy is not just another commodity and must not be so treated by government or industry. It is vital to any industrialized society. By virtue of its overriding importance to the economy, national security, and the well-being of the American citizen, we should recognize energy as a strategic material.

"This strategic material will require many new supply sources to replace oil," Gould continued. "The question before us is whether the transition path will be marked with traumas that shake our entire society or whether it will be a planned and relatively painless series of shifts and corrections. The answer is up to us. And the answer, again, is balance. Flexibility and diversification are the keys. And research and development of new technologies is the underlying hope."

Gould discussed next the environment question and wondered, "How do we provide electricity in the most cost-effective yet environmentally benign way? Environmental issues abound. And most of them are concerned with the results of what we've done in the past. Most of them, too, are now subject to regulation. We want to bring problems related to health effects down to socially acceptable levels of risk—and participate in the processes for determining what is socially acceptable. It is important for us, in this industry, not to be silent.

"Striving for a balance between environmental betterment and electricity at reasonable cost, we must develop technical methods to reduce and manage pollutants at acceptable public cost. And again, research is the key—research and development of new options, new processes, and new information. We cannot meet the needs of the 1980s and 1990s with the technologies of the 1960s and 1970s."

And Gould concluded, "I'm proud to be part of an organization formed 10 years ago—with no precedent—by a very disaggregate industry to carry out a balanced, collective, and integrated mission. Today, after a decade of energy shocks and economic upheaval, the Electric Power Research Institute stands as a symbol of our industry's sense of national responsibility." ■

This article was written by Christine Lawrence, Washington Office.

Network Studies Acidic Precipitation

With EPRI assistance, 35 electric utilities across the country are operating a wide-ranging precipitation monitoring network covering the eastern and central United States. Initial reports on the network's findings are now available.

During recent years the electric utility industry has actively sponsored research on acidic precipitation. Much of this effort has been organized through EPRI. In the fall of 1981 an ad hoc group of 35 electric utilities established a precipitation chemistry monitoring network—the Utility Acid Precipitation Study Program, or UAPSP. The network consists of 20 stations located from Maine to Colorado and extends as far south as Georgia and Texas.

EPRI is providing technical management for UAPSP, and the Edison Electric Institute is handling administrative functions. The contractor for the actual measurements program is Rockwell International Corp. Technical managers for UAPSP at EPRI are Mary Ann Allan and Peter Mueller; both are in the Environment Assessment Department of EPRI's Energy Analysis and Environment Division.

UAPSP's purpose is to establish and maintain a long-term, high-quality precipitation chemistry monitoring network in order to establish temporal and spatial variability and trends. The program is designed to discern the differences, changes, or trends in precipitation acidity and chemical content over time and in different regions of the eastern and central United States. The goal is to provide the clearest possible picture of the chemical nature of precipitation. The design takes into account the existence of other major monitoring efforts of a similar nature (e.g., daily sampling), as well as meteorologic, climatologic, topographic, and air quality factors. Data collected by UAPSP are being incorporated into national data bases for use by the scientific community.

UAPSP evolved from the nine-station precipitation chemistry monitoring program conducted as a supplement to EPRI's Sulfate Regional Experiment (SURE) from August 1978 to December 1980. (EPRI's precipitation network was reduced to five stations in 1981 as an interim measure until UAPSP became operational.)

Under UAPSP, precipitation samples are collected on a daily basis whenever precipitation occurs, and the pH, conductivity, and weight of the sample are measured at the site. The samples are then shipped to the Rockwell analytic laboratory, where an extensive chemical analysis is conducted. This analysis includes measuring pH, conductivity, total and strong acidity, sulfate, nitrate, chloride, phosphate, ammonium, sodium, potassium, calcium, and magnesium ions.

Rockwell maintains an extensive quality control program on all aspects of data acquisition. Tests are conducted continually to maintain the operations within specifications and to retrospectively establish the accuracy and precision of each measurement. All the procedures, methods, and assumptions associated with network operations are documented. The data are then archived and reported quarterly to EPRI.

A major criticism of earlier monitoring efforts of this type concerned the lack of assurance that the data collected were of known quality. UAPSP has addressed this concern by establishing a separate contract to determine whether or not the network is being operated according to specifications. This activity—being conducted by the Research Triangle Institute (RTI)—provides an audit of sampling, analysis, documentation, and data-handling processes. Thus, TRI examines the quality of the data independently from the measurement contractor. Through these efforts, UAPSP is expected to provide one of the most reliable data bases available on precipitation chemistry.

The UAPSP quality assurance program is compared with three other monitoring networks—EPA's MAP3S network and programs operated by Florida and Wisconsin utilities. Through a cooperative exchange of information, RTI evaluates the comparability of data from these networks with the data from UAPSP. If the programs are found to be comparable, the inclusion of these networks will provide a much larger base of high-quality data on acidic precipitation.

Plans call for the program to operate through the end of 1987. Annual determinations will then be made as to the need to continue and/or modify the study.

All information generated by UAPSP is available on request. Three reports have been published to date: a report describing the proceedings of an advisory workshop on methods for comparing precipitation chemistry data (UAPSP 100), a 1982 annual summary report of UAPSP activities (UAPSP 101), and a two-volume report of precipitation data displays for January 1, 1979, through June 30, 1982 (UAPSP 103). Reports may be ordered from the UAPSP Report Center, P.O. Box 599, Damascus, Maryland 20872. ■

A Tool for Detecting PCBs

Environmental concerns have become major and costly issues for electric utilities in recent years. One of these—PCB contamination—has been addressed by EPRI through an interdivision working group coordinated by the Electrical Systems Division. The result is a kit that can be used in the field by utilities to determine whether transformer oils contain significant quantities of PCBs.

According to EPA regulations, 20 million oil transformers now in use are presumed to be contaminated until proved otherwise. Until recently, utilities could not be sure a transformer had a PCB concentration below 50 parts per million (ppm), the level necessary to be classified as a non-PCB transformer, without laboratory analysis of an oil sample. The cost of analysis, however, was $50–$75 per sample, not counting the cost of collecting the sample. This represents an enormous cost.

More than two years ago, EPRI and General Electric Co. initiated an extensive project to identify and evaluate the techniques that could be adapted to measure low levels of PCB contamination in oil. As a result of the research, EPRI provided Horiba Co. with guidelines for modifying its existing sulfur-monitoring equipment to measure low levels of chlorine in transformer oil more rapidly and at lower cost. If chlorine content is less than 20 ppm, the PCB level is definitely under 50 ppm. Procedures and interpretation of chlorine measurements by using this device were then developed through extensive field tests and analysis.

By lending the prototype unit to several host utilities, EPRI showed that for under $3 per sample, 50–65% of the transformers in use can be identified with confidence as containing less than 50 ppm of PCBs. Several utilities have purchased and are now using this equipment.

EPRI then went a step further and developed a small, low-cost, disposable test kit—Clor-n-Oil—that can be easily carried and used on site to check chlorine content in oil. This screening device, along with the help of color change, indicates quickly if the transformer can be classified as non-PCB. Now, only when the chlorine content exceeds 20 ppm is it necessary to send the oil sample to a laboratory for further analysis.

This kit, prepared for EPRI by General Electric, has been lab-tested and is ready for field testing. Interested parties may contact EPRI Project Manager Vasu Tahiliani for more information. ■

EPRI Cosponsors Worldwide Safety Test

Along with organizations from the United States and eight other countries, EPRI finalized plans earlier this year to sponsor reactor safety tests in the loss-of-fluid test (LOFT) reactor facility in southeastern Idaho. The new series of LOFT tests is part of a worldwide program to demonstrate that the public risk from a major reactor accident is significantly less than is now widely presumed.

The LOFT reactor, operated by DOE, will investigate the consequences of a loss-of-coolant accident and identify preventive and palliative measures. The facility consists of a high-pressure containment building and a pressurized water reactor that can move out of the containment to a large "hot shop" for remote disassembly, inspection, and maintenance. The reactor generates no power, but has a power capacity equivalent to 55 MW (th). Its core and containment contain extensive instrumentation.

The new series of tests will study possible reactor accidents arising from a wide range of transients, according to Walter B. Loewenstein, deputy director of EPRI's Nuclear Power Division.

Eight countries in Europe and the Far East have joined in the three-year joint-sponsorship agreement for seven large-scale tests. The countries—all members of the Organization for Economic Cooperation and Development—are Austria, Finland, Italy, Japan, Sweden, Switzerland, United Kingdom, and West Germany.

Negotiations continue with Taiwan and other countries. EPRI is the private sector representative for the United States; DOE and NRC represent the federal government. EG&G Idaho, Inc., will carry out the project.

The project's total cost will be $91 million, of which EPRI will contribute $1.5 million. A project board and a technical advisory committee, with members from all participating organizations, will direct the research effort. EPRI's Loewenstein will serve on the board, and EPRI Program Manager Romney Duffey is a member of the committee. ■

CALENDAR

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

AUGUST

2–3
Seminar: Decision Framework for Air Quality Standards
Washington, D.C.
Contact: Dennis Fromholzer (415) 855-2741

9–11
Seminar: Equipment Qualification
Portland, Oregon
Contact: Robert Kubik (415) 855-8905

17–19
Human Factors for Assessing and Enhancing Power Plant Maintainability
Williamsburg, Virginia
Contact: Howard Parris (415) 855-2776

30
Seminar: TELPLAN Model
Washington, D.C.
Contact: Colleen Hyams (415) 855-2620

SEPTEMBER

12–13
Seminar: A Perspective on Decision Analysis for Senior Executives
Chicago, Illinois
Contact: Stephen Chapel (415) 855-2608

13–15
Seminar: Equipment Qualification
Dallas, Texas
Contact: Robert Kubik (415) 855-8905

20–22
Workshop: Heat Rate Improvement
St. Louis, Missouri
Contact: Anthony Armor (415) 855-2961

21–23
Human Factors for Assessing and Enhancing Power Plant Maintainability
San Mateo, California
Contact: Howard Parris (415) 855-2776

27–29
PWR Radiation Control
Palo Alto, California
Contact: Howard Ocken (415) 855-2055

OCTOBER

11–13
Value of Service Reliability to Consumers
St. Louis, Missouri
Contact: Ronald Wyzga (415) 855-2577

12–14
Seminar: Fuel Supply
New Orleans, Louisiana
Contact: Colleen Hyams (415) 855-2620

31
Seminar: FGD Chemistry and Analytic Methods
New Orleans, Louisiana
Contact: Dorothy Stewart (415) 855-2609

NOVEMBER

1–4
Symposium: Flue Gas Desulfurization
New Orleans, Louisiana
Contact: Tom Morasky (415) 855-2468

2–3
3d Annual Contractors' Conference on Coal Gasification
Palo Alto, California
Contact: George Quentin (415) 855-2524

2–4
Two-Shift Cycling
Chicago, Illinois
Contact: Frank Wong (415) 855-8969

13–16
1983 National Fuel Cell Seminar
Lake Buena Vista, Florida
Contact: Edward Gillis (415) 855-2542

DECEMBER

6–8
Seminar: PCB
Atlanta, Georgia
Contact: Gilbert Addis (415) 855-2286

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

RESIDUAL FUEL OIL DEPOSITS IN COMBUSTION TURBINES

Residual fuel oil usually costs less than distillate fuel even after the costs of sodium removal and magnesium treatment for corrosion control have been added to its price. However, magnesium, combined with other trace elements in residual fuel oil, tends to collect on turbine blades. These deposits inhibit efficient operation and are uneconomic in a number of ways. They reduce engine efficiency and power by clogging and distorting turbine passages. They reduce potential engine efficiency and power if the blade cooling system and the turbine inlet temperature are modified in order to lower the blade sensitivity to deposit formation. Deposits reduce plant availability by requiring plant shutdown for turbine washing when they become excessive. Results from EPRI projects show that for a given gas temperature, the deposit rate increases as turbine metal temperature decreases, until a maximum rate is reached. The deposit rate begins to decrease as the metal cools further and becomes small for low metal temperatures. For any given metal temperature, the deposition rate increases greatly with increasing gas temperature.

A number of EPRI projects have investigated deposit phenomena of residual fuel oil combustion products at low and high metal temperatures. General Electric Co. studied low-metal-temperature deposits (AP-1889, 2 vols.; AP-2650), using water-cooled vane cascade rigs with metal temperatures of 500–1200°F (260–650°C) and gas temperatures of 1850–2300°F (1000–1260°C). No. 2 gas turbine distillate fuel doped with ash components typical of washed and treated residual fuel oil was used for all tests. The fuel was doped to simulate the same ash load and SO_3 partial pressure that would result from operating a 12:1 pressure ratio utility gas turbine engine on a fuel containing 1 ppm Na, 100 ppm V, 300 ppm Mg, 10 ppm Ca, and 0.5% S.

Nine low-metal-temperature tests were run. The first-stage vanes, both in the engine and in the test cascade, are run choked—that is, with an average Mach 1 velocity through the narrowest flow area section so that the maximum possible rate of flow would pass through that area. The flow rate can be decreased either by constriction of the narrow section or by the loss in total pressure that results from surface roughness. Deposits cause both of these conditions. The main test result is the effective throat area—that is, the area through which the same choked flow rate would pass if there were no upstream pressure loss because of surface roughness. Thus the effective throat area takes into account both effects of deposition: the actual constriction and the loss in total pressure.

In a typical experimental test, after a period of fewer than 10 hours, the effective throat area is found to decrease at a reasonably uniform rate, which is called the initial constriction rate. Random spalling or deliberate cleaning can cause a sudden loss of ash. After such an upset, the constriction rate tends to be more rapid before returning to the initial rate.

Most of the tests were carried out at a gas temperature of 2050°F (1120°C); however, one test was also conducted at 1850°F (1010°C) and one at 2300°F (1260°C). Test data show a very sharp drop in the deposit rate with decreasing metal temperature; there was virtually no deposit below 650°F (260°C). Conversely, there is a very high deposit rate at around 1200°F (650°C).

On-line cleaning procedures were tested by using two differently sized nutshells, coke particles, and water spray, as well as off-line water washing. The most effective on-line cleaning procedure was found to be a combination of large nutshells and coke particles fed into the system during fired operation. These on-line procedures were more effective at very low metal temperatures. They were only partially effective at the higher metal and gas temperatures. System shutdown with water wash and refiring was completely effective in deposit cleaning for all temperature conditions tested.

General Electric also obtained higher-metal-temperature data by using an air-cooled rig similar in geometry to the water-cooled rig and tested in the same facility. However, most of the high-metal-temperature data were obtained from a Westinghouse Electric Corp. project (AP-2739). This project did not use a vane cascade but instead used an array of hollow cylinder test specimens placed in a pressurized combustion tunnel with air coolant flowing through the hollow center. This procedure does not produce quantitative results as in the General Electric tests, but it does test more conditions and determine relative deposit rates. These tests used real residual fuel oil from Florida Power & Light Co.'s Putnam station fuel tanks, washed to reduce the alkali content. Before testing, the

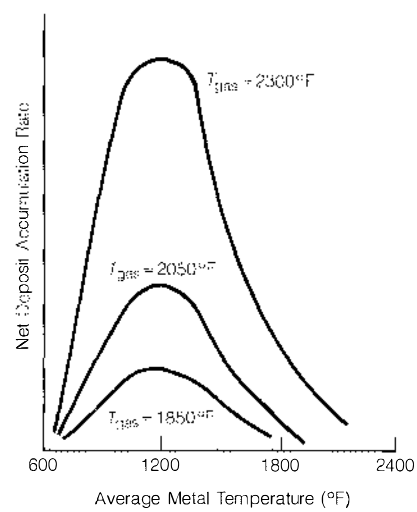


Figure 1 Deposition rate trends as a function of gas and metal temperatures. Gross deposition rate increases with increasing $T_{gas} - T_{metal}$. However, there is loss of surface adherence at low metal temperatures. Thus a peak net deposition rate is reached at approximately 1200°F (650°C). The overall deposition rate increases greatly with increasing gas temperature.

fuel was treated with magnesium-containing additive for vanadium control.

Results show that for a given gas temperature the deposit rate increased greatly as the metal temperature decreased in the 1600–1350°F (870–730°C) range. The deposit rate for a given metal temperature also increased greatly with gas temperatures over 1900–2300°F (1050–1260°C).

Figure 1 shows the relationships from all the test data. The deposit rate increases as the metal cools (starting from equal metal and gas temperatures) to a metal temperature in the 1200–1000°F (650–550°C) range. The deposit rate drops sharply with further decrease in metal temperature. The ease of cleaning, especially on-line cleaning, also improves when the metal temperature drops below 850°F (450°C).

The deposit rate increases rapidly as the gas temperature increases, especially above 2000°F (1100°C). The deposits tend to be denser, harder, and more difficult to clean, except when the metal temperature is very low. *Project Manager: Arthur Cohn*

COOL WATER COAL GASIFICATION PROJECT

*Changing circumstances over the last decade have brought about corresponding changes in planning for fuels used to generate electricity. Oil and natural gas price and supply uncertainties and the increasing limitations on nuclear power have prompted renewed interest in coal. However, new technologies are needed to reduce the effects of coal-based power plants on the environment. One such technology is coal gasification, which produces a clean, easily handled fuel gas for burning in fairly conventional generating equipment. A particularly efficient way of applying this technology is by integrating the Texaco gasification process with a combined combustion turbine–steam turbine generating unit. Integrated gasification–combined-cycle (IGCC) systems are cost-competitive with direct-coal-fired power plants, and EPRI-sponsored pilot-scale tests have confirmed gasification's environmental benefits. The modular nature of IGCC systems would also allow utilities to add generating capacity in small increments to meet the reduced load growth forecasts of recent years. The first effort to demonstrate this new IGCC technology on a commercial scale, the Cool Water project, is within budget and on schedule for a mid-1984 plant startup. An earlier status report discussed funding, project objectives, general plant design, and major supplier selections (*EPRI Journal, *April 1981, p. 39), and an EPRI report (AP-2487) presents detailed information on project organization and management structure, system design (including plant layout and comprehensive flow diagrams), performance projections, cost estimates, and schedule.*

Mid-1981 delays in fund raising slowed the project engineering effort and postponed construction for several months. In December 1981 the EPRI Board of Directors acted to substantially increase EPRI's financial contribution to the project. This increase, additional commitments from the other participants, and funds from new participants allowed plant construction to begin. The new financial commitments include an increase in EPRI funding to $65 million, with an obligation to provide up to $40 million more if needed, an increase in Texaco Inc.'s funding to $45 million, increases in Bechtel Power Corp.'s and General Electric Co.'s commitments to $30 million each, an additional $6 million of facilities to be contributed by Southern California Edison Co. (SCE), bringing its share to $31 million, and new commitments of $30 million and $5 million, respectively, from the Japan Cool Water Program Partnership and the Empire State Electric Energy Research Corp.

With additional funds available, detailed design resumed at a rapid pace. The Bechtel home office and engineering workforce grew to a peak level of about 220 by mid 1982 before beginning a steady reduction consistent with the schedule requirements. By mid 1983 this staff is expected to be fewer than 50, with about 95% of the engineering effort having been completed. The detailed scale model of the demonstration plant was completed in late 1982 and shipped to the construction site. All necessary design drawings have been issued and virtually all equipment items, as well as most bulk materials, have been ordered. Approximately 70% of the equipment and materials have been delivered to the site. The remaining engineering and procurement tasks are mainly ordering spare parts, coordinating required vendor documentation, and responding to field requirements and inquiries.

Construction has also been proceeding rapidly as necessary drawings and materials have become available. Bechtel's on-site staff has grown steadily over the past year and a half to its present peak level of about 600. In addition, nearly 100 subcontractor personnel have been working on site, and a separate workforce is busily erecting Airco, Inc.'s air separation plant, which will supply oxygen to the IGCC demonstration facility.

Construction is more than 50% complete (Figure 2). Equipment already erected or set in place includes the rail spur; coal receiving hopper; various coal conveyors; coal silos; grinding mills and slurry preparation equipment; slurry charge pumps; carbon scrubber; all process columns and vessels for sulfur

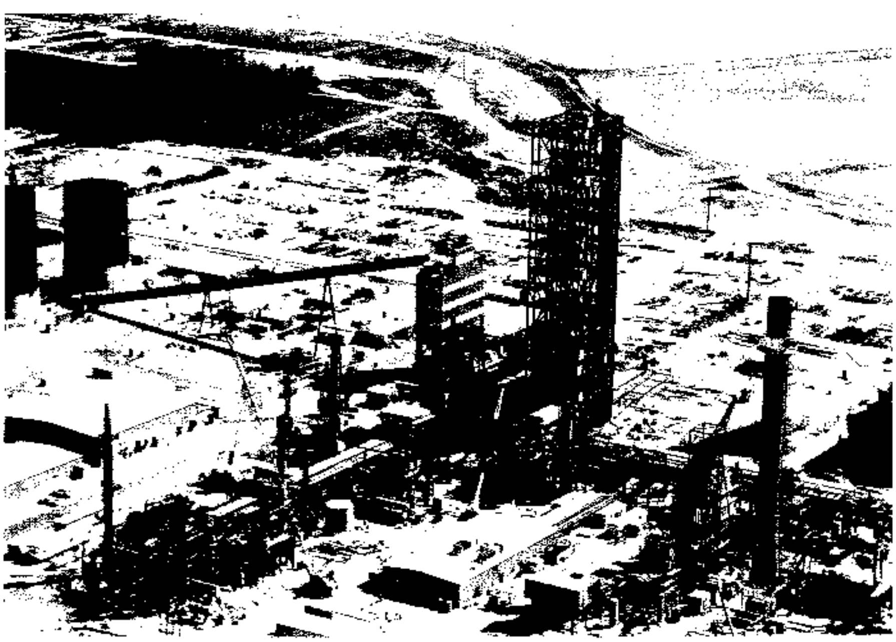


Figure 2 IGCC demonstration plant under construction at Southern California Edison's Cool Water generating station, located near Barstow, about 120 miles northeast of Los Angeles.

removal and recovery and tail gas treating areas; the saturator tower; most heat exchangers and pumps; the gas turbine generator; heat recovery steam generator; steam turbine generator; and cooling tower. Although the structure for the gasifier and the synthetic gas coolers has been erected, these critical vessels are not due at the site until late this year. Construction completion and plant startup are scheduled for June 1984.

The complete project was estimated in June 1982 to cost $294 million. A subsequent estimate at the end of 1982 showed that this budget, which included significant contingency funds, remained valid. Continued careful cost monitoring indicates that the project is within budget.

A staff organization for project operations and testing has been developed and agreed upon. Key supervisory personnel have been identified, and several of these individuals are already working at the site to review plant design and construction and to begin the planning necessary for equipment and system commissioning. All operating manuals have been drafted and are being approved. Safety procedures have been prepared and thoroughly reviewed. A number of training programs have been established, and the first plant operators have begun instruction.

SCE and Texaco are primarily filling operating and maintenance supervisory positions. Other project participants are providing some technical support staff. Hourly employees are being supplied entirely by SCE.

EPRI is providing the supervisor for the test and demonstration group. This important role carries the responsibility for satisfying the project test objectives and provides EPRI with the opportunity for firsthand assurance that project goals will be met. The tests and evaluations to be conducted will include overall efficiency, environmental performance, steady-state operability, transient response, equipment reliability, system availability, materials life, and short-term performance with alternative coals of varying compositions.

EPRI participates in project management through membership on the Board of Control and the Management Committee. Technical advice is supplied by representation on the Operations, Materials, and Test and Demonstration Advisory subcommittees. (EPRI chairs the last two groups.) The Institute monitors finances by membership on the Audit Subcommittee. Day-to-day input on project controls, procedures, quality assurance, and overall design implementation is provided by the EPRI resident manager at the Daggett, California, plant site.

Like so many alternative energy development efforts, the Cool Water project has been affected by the drop in oil prices in the last year. The California Public Utilities Commission ruling in 1980, reconfirmed in 1981, limited SCE's recovery of its project-related costs from its ratepayers to the avoided-cost value of the electricity produced by the demonstration plant. The unexpected oil price reduction and resulting lower avoided-cost projections increased the financial risk associated with the project. To counteract the effects of the oil market, the project participants applied to the U.S. Synthetic Fuels Corp. (SFC) for financial assistance. The resulting letter of intent signed by SFC and the Cool Water program in April 1983 provides for up to $120 million in price support over a five-year period for the synthetic gas that will be produced during project operation and purchased by SCE. *Project Manager: T. P. O'Shea*

GEOTHERMAL WELLHEAD CONVERSION

By building a small (less than 10-MW) power plant at the site of a geothermal well, a utility can gain experience and data useful for decisions on full-scale geothermal field development. A smaller plant requires less capital than does a 50- or 100-MW plant, and such a venture produces both data and revenue earlier in development. EPRI has tested the first such power system in the United States and is starting a major new geothermal project to evaluate several other wellhead power systems.

A wellhead power system is one that accepts the full flow of at least one geothermal well and converts the thermal energy into electricity right at the site of the well. This concept contrasts with the central power plant approach currently used in developing large generating capacity systems at geothermal fields in the United States, the Philippines, Mexico, Japan, and El Salvador. Generating units at these highly developed geothermal fields, are typically larger than 50 MW (e) and accept the flow from 10 or more wells. New Zealand and Italy use smaller central power plants; 10- to 30-MW (e) units are common. Larger unit sizes are more economical, especially for the typical plant that is custom-designed and then constructed at the site. However, EPRI and electric utilities with geothermal prospects believe the first unit in a new geothermal field will be a small one that converts the energy flowing from a single geothermal well. Wellhead power systems at high-temperature geothermal fields (250°C, 482°F) are expected to have a generating capacity of 5–10 MW (e). Such systems will be smaller at moderate- or low-temperature fields: about 3–5 MW (e) at 180°C (356°F) and only 0.5 MW (e) at 130°C (266°F).

These smaller wellhead conversion systems could be shop-fabricated, transported to the site, installed, and placed in operation. During operation, valuable information can be obtained, including data relevant to determining reservoir size, production well flow rate and temperature during long-term operation, injection well performance, corrosion and scale formation, and effects of noncondensable gases. By obtaining this information early in geothermal field development, a utility can reduce the costs and risks of future development. In addition, the wellhead system can be used again at another site.

In 1979 EPRI initiated the first U.S. wellhead power system project by awarding a contract to Biphase Energy Systems, Inc., to design a wellhead rotary separator–turbine (RST). After Biphase completed the conceptual design, it cofunded the detailed design and construction of the wellhead RST. In 1981 Utah Power & Light Co. (UP&L) joined the project as host utility and installed the 1.6-MW (e) unit at the high-temperature, 260°C (500°F) geothermal field near Milford, Utah (*EPRI Journal*, September 1982, p. 38). EPRI, UP&L, and Biphase shared the cost of testing the RST part of the wellhead system from August 1981 through April 1983 (RP1196). Phillips Petroleum Co. supported the testing by providing a geothermal fluid supply to the RST. Phillips is the operator of the Roosevelt Hot Springs geothermal field. A 20-MW (e) single-stage direct-flash power plant and fluid supply system is being constructed at the site by UP&L and Phillips.

Figure 3 shows the wellhead RST system in operation. At design conditions the RST was to produce 1600 kW (e). Since the RST converts only the kinetic energy in the liquid stream to electricity, to complete the wellhead system a steam turbine could be added to produce additional power from the steam flowing out of the RST. An additional 5200 kW (e) would be generated if the flow entering the RST were a two-phase mixture with an 0.08 steam fraction (by weight), had a pressure of 2760 kPa (400 psia), and flowed at the design flow rate of 65 kg/s (515,000 lb/h). The flow from the well at Milford was closest to design conditions during the performance test runs made in August 1982. Tests at the above conditions resulted in the following comparisons of design and measured values.

- Output power from the RST was 1330 kW (e), compared with a design value of 1600 kW (e).

□ Of the 270-kW (e) shortfall in power output, 130 kW (e) is accounted for by lower machine efficiency. Efficiency was 32% instead of the design value of 35%. The remaining 140-kW (e) shortfall resulted from a lower wellhead fluid enthalpy than the design value.

□ If a steam turbine (ST) had been run on the steam from the RST, total power output of the RST–ST system would have been 1.14 times that of a single-stage direct-flash unit, compared with a design goal of 1.20.

To map the performance of the RST as a function of the most critical variations in flow conditions, the RST was operated at various inlet and outlet pressures. The inlet pressure is the pressure of the two-phase steam and water mixture at the RST inlet. The outlet pressure is the pressure of steam in the RST housing. In a complete wellhead power system, this steam would be sent to a steam turbine to produce an additional 5.2 MW (e) of electric power. Figure 4 summarizes the results of this performance test by showing the trend of machine efficiency as a function of the two independent variables most critical to RST performance: (1) the inlet steam fraction, which is determined by the enthalpy of the fluid produced by the reservoir, and (2) the pressure ratio across the RST, absolute inlet pressure divided by absolute steam outlet pressure. Constraints on the combinations of these pressures actually available from the well have resulted in steam fractions (qualities) ranging from 0.054 to 0.089 and pressure ratios ranging from 6.0 to 12.0. Figure 4 is based on the data available from four-nozzle operation and on extrapolations of trends noticed when fewer nozzles were used in order to get higher inlet pressures (and, hence, lower inlet steam fractions). The measured isentropic efficiencies indicate a 1.20 resource utilization improvement for an RST system, compared with an optimized single-stage direct-flash power system.

After the performance tests were completed in October 1982, the RST was operated continuously at steady-state conditions for an endurance test. The test goal was to operate the RST for a total of 4000 hours, including all performance test hours since unit startup in October 1981. The endurance test was completed on April 2, 1983, after 4004 hours of operation had been accumulated. The availability factor of the RST itself during this endurance run was 98%. The factor for the entire wellhead power system was 94%. These availability factors were derived from the following record.

A =	Operating hours during endurance run	3160
B =	Hours lost due to RST itself	70
C =	Hours lost due to generator	133
D =	Hours lost due to external system (grid)	17
E =	Hours lost due to other operations at the test site	380
F =	Total elapsed time in hours	3760

RST availability factor:

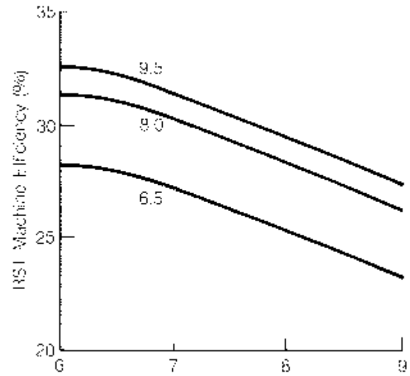
$$\frac{A}{A+B} = \frac{A}{F-C-D-E} = 0.978$$

Wellhead power system availability factor:

$$\frac{A}{A+B+C} = \frac{A}{F-D-E} = 0.940$$

The total amount of electricity generated by the RST over the 17-month period from October 1981 through March 1983 was 3270 MWh. The net electricity delivered to the UP&L system was 2770 MWh. Power production was below the 1.0 MW (e) level during most of the endurance test because the geothermal fluid flow rate was reduced due to factors not related to the RST test. *Project Manager: Evan Hughes*

Figure 4 Isentropic efficiency of the RST as a function of steam fraction at the RST inlet and pressure ratio across the nozzle (inlet pressure divided by outlet pressure equals 6.5, 8.0, and 9.5). Isentropic efficiency is the ratio of the actual work output of the RST to that of an ideal isentropic cycle operating across the same pressure difference from RST inlet to steam outlet. For a 250°C (482°F) geothermal resource, a 30% isentropic efficiency makes possible a 20% increase in electricity output for an RST power system, compared with an optimized single-stage direct-flash power system.



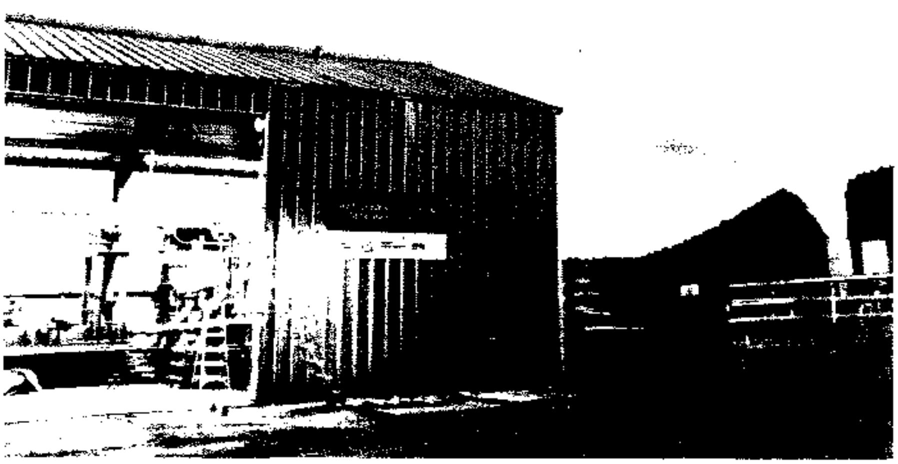


Figure 3 RST power system in operation at the Roosevelt Hot Springs geothermal field near Milford, Utah. The skid-mounted RST occupies the end of the building just to the right of the large open doorway. The smaller lube oil skid is at the rear of the building, opposite the doorway. Steam separated by the RST from the steam-water mixture flowing from the well is being vented to the atmosphere through one of the two silencers shown at the right-hand edge of the photograph. A steam turbine could be added to the system to generate power from this steam. A complete system operating at design conditions would produce 1.6 MW (e) from the RST, plus an additional 5.2 MW (e) from a steam turbine.

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

FGD CHEMISTRY

Flue gas desulfurization (FGD) systems used by coal-fired power plants to control emissions of SO_2 have shown varying degrees of reliability over approximately 15 years of operating these systems. Some improvement in operability has been achieved, but generally as a result of higher maintenance costs. Because many of the causes of poor reliability are related to the chemistry of these systems, a comprehensive study of the chemistry is one of the major projects in the Desulfurization Processes Program. As over 85% of the operating FGD systems are based on absorption of SO_2 in aqueous lime or limestone slurries, the research has concentrated on the study of these systems. The goal of this work is to produce sufficient basic data so that a computer simulation model of the chemical processes can be developed.

The initial study reviewed all existing data and identified the basic data needed for modeling (RP1031-1). On review of the data, it was obvious that most of the information about FGD systems was obtained from pilot plants of specific configuration and operating conditions. Many basic data were unavailable for sections of the FGD processes, such as reagent preparation, mass transfer, buildup of impurities, oxidation of sulfur species, crystallization of sulfur-containing products, separation of solids, and scaling of surfaces in the equipment.

Another problem surfaced when available chemical composition data were subjected to a test for accuracy. The values were considered inaccurate if the equivalent number of cations did not balance the equivalent number of anions to within 10%, relative. When this simple test was applied, many experiments and pilot plant tests had to be discarded. A number of reasons for these discrepancies are possible; however, one probable cause is in the accuracy of the analytic methods used. Few of the published methods for chemical analysis of FGD streams include accuracy and precision data. These data can be used to calculate the expected quality of chemical determinations. To eliminate the question of analytic method accuracy and precision, Radian Corp. is preparing a handbook of FGD analytic methods that will give accuracy, precision, interferences, and acceptable concentration ranges for each method given (RP1031-4). A total of 55 methods—18 physical property determinations and 37 chemical species determinations—will be included in the handbook. All methods will have single laboratory precision data, and seven of the commonly used methods will have interlaboratory precision data. Twenty-two utility laboratories are participating in these interlaboratory precision studies. The publication of the handbook is planned for the last quarter of 1983.

Development of basic data for FGD chemical modeling required EPRI to initiate several studies. The University of Arizona determined nucleation and growth rates for both gypsum (calcium sulfate dihydrate) and calcium sulfite (a calcium sulfite/sulfate hemihydrate). One or both of these solid phases can be present in FGD slurries, depending on operating conditions. The rates for gypsum crystallization, including the effects of some additives, were reported in EPRI CS-1885. Using these rates in a crystallizer design computer model showed that the crystal size distribution of gypsum from oxidized FGD liquors could be controlled by using a draft-tube, double-draw-off crystallizer. (This crystallizer configuration was patented for FGD use by the University of Arizona and EPRI.) Similar information on calcium sulfite solids indicates that the crystal size of this solid phase can be increased by using the same crystallizer configuration. Final reports of this sulfite work will be published during 1983.

Impurity concentration

Another area of research has been to determine the effects of the concentration of impurities on the SO_2 removal process. As the operators of FGD systems improve process control and reduce losses of liquor from the system, impurities from the flue gas, makeup water, and reagent can concentrate to fairly high levels in the various process streams. In some cases, plants must also reduce water consumption and/or waste discharge, forcing reuse of waste streams as makeup to the wet scrubber. To simulate the steady-state process stream concentrations, calculations were made by using Radian's FGD material balance computer program to determine the effects of variations in the composition of coal, water, cooling tower blowdown, lime, and limestone (CS-2451). Results showed that increased concentrations of impurities are not necessarily detrimental because some ions can increase liquid-phase alkalinity and improve SO_2 removal. Chloride can cause problems (decreased alkalinity, as well as increased corrosion) in a calcium-based system when chloride concentrations reach ~30,000 ppm. However, with a chloride content of coal at 0.1%, a maximum chloride concentration of <30,000 ppm was calculated. This level has little effect on calcium systems but can affect systems that depend on magnesium or sodium to increase alkalinity because chloride decreases the alkalinity unless the magnesium or sodium increases by an equivalent amount. Chloride concentration can be even higher than the 30,000 ppm calculated previously, depending on the chloride level in the coal.

Because of the potential effects of chloride, studies of the effects of dissolved solids on FGD systems are in progress (RP1031-4). The concentration of various ions in solution can alter the solid phase composition, particularly that of hydrated compounds. Testing up to 24% dissolved solids as combinations of Ca^{++}, Mg^{++}, Na^{+}, Cl^{-}, SO_4^{--}, and SO_3^{--} has shown that the same solid phases, gypsum and calcium sulfite hemihydrate, precipitate over the entire range of impurity type and concentration.

There are effects on SO_2 removal, however, that vary with the type and concentration of impurity. Experiments in a bench-scale scrubber, simulating a limestone system producing calcium sulfite solids, have been completed. Chloride concentrations up to 140,000 ppm dissolved were used. Increasing the chloride concentration resulted in decreased SO_2 removal under the same operating conditions (Figure 1). When chloride was added as magnesium chloride ($MgCl_2$), the reduction in SO_2 removal was not as great as when chloride was added as calcium chloride ($CaCl_2$). When chloride was added as sodium chloride (NaCl), intermediate values between $MgCl_2$ and $CaCl_2$ were obtained. Simulating a forced oxidation system producing gypsum solids showed similar results. The SO_2 removals were similar to those of the unoxidized system, but differences between chloride types were not as great. The same trends were observed when the reagent was lime slurry.

The detrimental effects of chloride on the FGD system SO_2 removal can be mitigated by several means. One obvious way is to decrease the chloride level by removing the chloride prior to the SO_2 absorber. However, preremoval systems are an extra cost and are subject to corrosion problems. Another way to increase removal of SO_2 in the presence of high chloride is to increase the liquid-to-gas ratio (L/G) so that greater dissolved alkali contacts the gas stream. A 3–5% increase in SO_2 removal was observed by increasing the L/G from 41 gal/1000 ft³ (5.5 L/m³) to 80 gal/1000 ft³ (11.0 L/m³). The use of reagent lime or limestone with soluble magnesium compounds will also increase the SO_2 removal. For existing systems where changes in operating conditions are difficult, an additive such as adipic acid buffer can be used. The quantity of adipic acid required to maintain constant SO_2 removal while increasing chloride concentration as $CaCl_2$ is about 200 ppm at 60,000 ppm of chloride, increasing to about 1500 ppm with 140,000 ppm of chloride.

FGD reagents

Magnesium dissolved in FGD liquors is beneficial to SO_2 removal because magnesium sulfite has greater solubility than calcium sulfite, increasing the dissolved alkalinity. Previously, it had been presumed that magnesium carbonate ($MgCO_3$) in limestone was present as dolomite and was insoluble in wet scrubber systems. Therefore, magnesium was added as a separate compound even if present in the limestone. Preliminary investigation of the solubility of magnesium-containing limestones indicated that the presumption of $MgCO_3$ insolubility was not accurate. To determine if sufficient deposits of magnesium-containing limestones were available for use in FGD systems, a survey of the U.S. deposits of magnesian limestone (3–10% $MgCO_3$) was completed by Dravo Lime Co. (CS-2783). The majority of these limestones occur in the eastern half of the United States. Thirteen of the formations were sampled for further study. Of these, eight were identified as having potential for FGD use.

Radian studied the solubility of $MgCO_3$ and calcium carbonate ($CaCO_3$) from the magnesian limestones sampled in the limestone survey (RP1031-4). Effects of variations in operating conditions on the rate of solution were determined for eight limestones, five of which contained >2% $MgCO_3$. The dissolution rate for the $MgCO_3$ was always less than that of the $CaCO_3$ but varied from stone to stone. Variable operating conditions that increased the dissolution rate of both $CaCO_3$ and $MgCO_3$ are increasing temperature, decreasing pH, increasing agitation, and decreasing particle size.

Because particle size is an important factor in the solubility of limestone, the ease of grinding limestone (grindability) was investigated. As part of this study, limestone formations, compositions, production, and quarry locations in the United States were surveyed. Thirty of these limestones, representing a wide variety of such properties as geologic age, composition, location, and microstructure, were tested. A test was developed to produce a grindability index that correlated well with the more complicated Bond Work Index. The grindability did not appear to correlate with any of the chemical and physical properties of limestone except for a correlation with some factors relating to microstructure. Thus, it may be difficult to predict ease of grinding without a grindability test.

The data from the grindability study were used to select the limestone to be used in comparing four different commercial grinding systems (RP1877-1). This work will be completed in 1983 and results will include cost comparisons of the various grinding systems.

Continuation of FGD chemistry research will include development of an FGD simulation model and verification of the model and laboratory data in a pilot plant. DOE sponsored some initial work on an FGD model, but no longer sponsors this project. However, the DOE model will be the basis for further development to save time and expense. The pilot unit is expected to start in late 1983 or early 1984 and will be located at a power plant that burns high-sulfur eastern coal. *Project Manager: Dorothy Stewart*

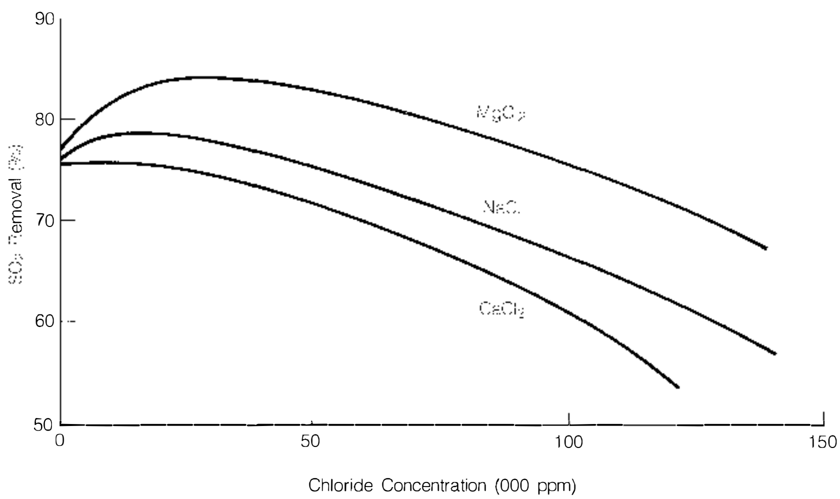


Figure 1 SO_2 removal is decreased with increasing chloride concentration. However, the effect is altered by the cation associated with the chloride. Magnesium and sodium allow higher alkalinity as sulfite, which results in higher SO_2 removal than when calcium is the cation.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

POWER SYSTEM PLANNING AND OPERATIONS

Coping with strained systems

Economic and regulatory limitations have deferred many power system reinforcements. At the same time, some systems are being used to transfer large amounts of power to load centers from distant, more economic power plants in unanticipated volume. Thus, the existing structure must bear more weight than ever before. As these trends continue and load grows (even at a small rate), some systems are being pushed closer to their limits.

Five projects summarized below are aimed at helping utilities cope with leaner and therefore weaker power systems by the following activities.

- Identifying key steps and development needs in planning and operating procedures and analytic tools
- Improving existing simulation capabilities to more closely match real conditions, thus improving the ability to predict system response and permitting operation closer to system limits
- Developing the ability to predict system response more quickly, thus providing planners and operators the necessary time to react to unforeseen events

In a contract with Westinghouse Electric Corp., present practices, procedures, and research needs were evaluated and recommendations were made to minimize the impact of electrical islanding, which leads to uncontrolled loss of load (RP1952). The most significant conclusion is that maintenance procedures (often neglected during hard economic times) can have the most immediate and important impact. The second significant conclusion is that methods that provide predictive and suggested corrective actions to changing conditions are a prime research need. The final report will be available later this year.

At Michigan State University, researchers are developing ways of quickly predicting the impact of the sudden loss of a generator on large interconnected networks (RP1999-1). If not properly prepared for such an event, automatic relays can incorrectly remove facilities from service, thereby exacerbating the situation. This is especially important today because of the current trend toward large generating units and long-distance power transfers. Methods for finding the weak links in the network are also being developed. Once recognized, these weaknesses can be overcome. Final report and computer programs will be available in early 1984.

At Purdue University, current approximations of simulating unbalanced faults (non—three phase) in transient stability programs are being tested (RP1999-2). No investigation has ever been performed to gauge the amount of error incurred from use of these approximations. The results, using the common fault representation (symmetrical components) now in the Philadelphia Electric Co. stability program, are being compared with those produced by a complete, accurate, three-phase model on a hybrid simulator. If this comparison shows any shortcomings, an improved unbalanced fault model will be developed and tested for use in transient stability programs. The final report will be available in early 1984.

Design limitations for equipment and systems are often caused by very high speed or electromagnetic transients. A computer program called EMTP (electromagnetic transients program) is widely available for this type of simulation, but widespread use has been limited by its complexity and poor documentation. Westinghouse is studying what improvements would best simplify its use while increasing the benefits derived (RP2149). Early results indicate that improved documentation, simplified input, and user education would yield sufficient payback for every dollar invested in program improvement. The final report for this project will be available in early 1984.

Ontario Hydro is testing a method for calculating the stability of a power system without today's expensive, time-consuming, step-by-step simulation—that is, a way to calculate stability directly (RP2206). The computer programs developed in an earlier EPRI project (RP1355-3) are being expanded to accommodate 1500-bus systems. The new method will be extensively tested, including comparisons with traditional analytic methods, using four different test cases. Experience from this test will be used to demonstrate applications and shortcomings, if any, of the new technique. A first-swing stability analysis tool that runs as fast as a comparable load flow has many applications in on-line dynamic security monitoring and operations planning, as well as being a screening tool in expansion planning. First large-scale test results will be available in early 1984. *Project Manager: J. V. Mitsche*

OVERHEAD TRANSMISSION

Wood pole maintenance and reliability assessment

Are new poles as strong as those that were bought 20 years ago? How strong are existing, in-service wood poles? When should they be economically replaced? Can they be stubbed or repaired more economically? How does the change of strength affect the overall reliability of a transmission or distribution pole line?

For five years EPRI has been seeking answers to these perplexing problems as part of a research project on the reliability-based design of transmission lines (RP1352). This project has now succeeded in producing significant and usable results for the industry.

The lack of an adequate data base upon which to base strength estimates for poles in service led to EPRI's implementation of a full-scale wood pole pilot testing program. As part of this pole-testing program, selected utilities were asked to donate wood poles from transmission lines that were being removed from service so that the degradation of fiber stress could be determined and correlated with time in service. Over 225 of these poles have been tested to destruction in the Colorado State University testing laboratory. To be able to quantify the loss of strength of a wood pole with time in service, it was imperative that the strength of new poles be determined also, thereby providing a baseline for industry use. With the assistance of the Southern Pressure Treaters Association and the Western Wood Preservers Institute, 282 new southern pine and Douglas fir poles were donated to the project by pole suppliers, a significant investment and contribution on their part. Thus far, all 122 southern pine and over 120 of the 160 Douglas fir poles have been tested. A complete report containing the results of the tests on these new transmission-size poles, tests on the utility-donated in-service poles, and previous tests on over 3000 distribution-size poles is expected to be available from the Research Reports Center shortly.

Although determining the strength of wood poles through full-scale destructive tests is important to this project, the ultimate goal is to develop a nondestructive evaluation (NDE) procedure that can be used in the field on in-service wood poles and will indicate the amount of remaining usable strength. Such a procedure has been actively pursued by wood researchers all over the world, but with little success to date.

A major first step in developing a meaningful NDE test of in-service wood poles is to measure the speed of a sonic wave as it passes through a pole. By correlating full-scale destructive tests of poles with the speed of a sound wave as it passes through the pole, the distribution of material strength throughout a pole can be ascertained; an entire line of in-service poles can be so tested. This procedure uses the computer program STADSIM (statistical distribution simulator), available shortly from the Electric Power Software Center. The excellent correlations that can be developed by using this procedure can be seen in Figure 1, where the frequency distributions of strength developed by actual full-scale destructive pole tests are compared with the simple NDE procedure. This example is from one of Kansas Power & Light Co.'s wood pole transmission lines.

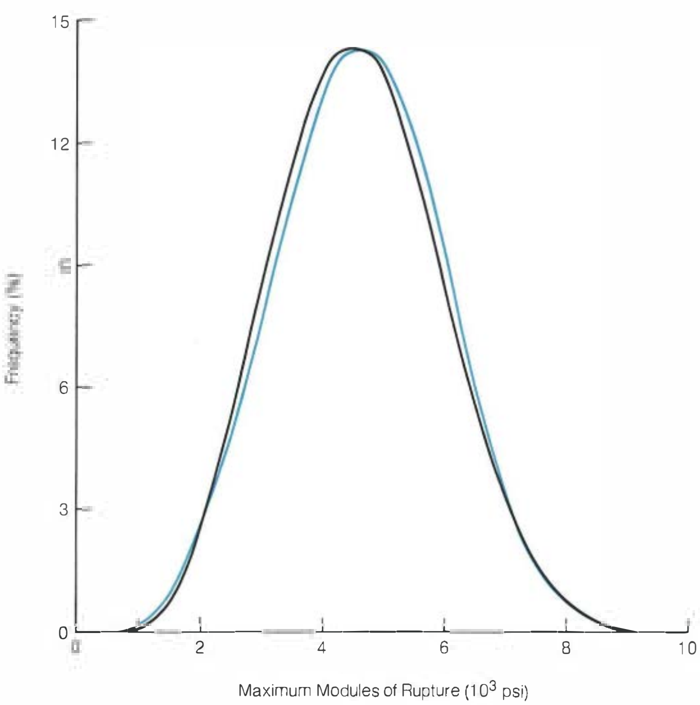


Figure 1 Comparison of frequency distributions of strength developed by actual full-scale destructive pole tests (black; $n = 82$) with the predictions made by using a simple NDE technique (color; $n = 2500$).

Although the NDE procedure accurately predicts the frequency distributions of material strength for poles in an entire line, the procedure has one major drawback: the weak poles in a line cannot be identified because of the substantial amount of scatter that exists in the raw data. However, a major breakthrough by researchers at Colorado State University correlates spectral wave analysis of the sonic wave that has been passed through the pole with full-scale destructive pole test results, enabling them to predict the fiber strength of a pole to within 500 psi (3.4 MPa). This NDE procedure is still limited to the laboratory, but with utility assistance, it can be moved into field practice and thereby improve utility wood pole maintenance. Further, when coupled with reliability-based design and analysis techniques, this procedure can provide a running assessment of the structural reliability of both transmission and distribution wood pole lines.

Now utilities can not only develop more accurate data on the strength of their pole lines but also make those data more meaningful and relevant to their service territory. One of the basic failure mechanisms in wood is based on cumulative extreme loading, which causes progressive failure of the wood fibers in the pole. Thus, the differences in climatic conditions and the variety of external loads to which each utility's poles have been subjected are important factors.

To assist utilities in gathering these important data and to provide the field calibration required for the use of this NDE device, the Research Institute of Colorado (with the principal contractor, Engineering Data Management) will construct a mobile testing vehicle for the full-scale testing of wood poles in the field. This effort will not be funded by EPRI; rather, the expenses of developing the NDE correlations and of creating a wood pole data base for each utility will be recovered by direct contracts with participating utilities, based on a fixed charge for each pole tested. Because the data bases for the strength of new southern pine and Douglas fir wood poles have already been developed, only those poles that have been in service for an extended period of time will have to be included in this test program. It is imperative that poles representing a wide range of service life be tested, because the loss of strength with time is an

Table 1
FULL-SCALE WOOD POLE TEST PROGRAM

Test	Nondestructive evaluation
	Full-scale bending to destruction
No. of poles	50–75 per species at each test site
Site requirements	200 × 200 ft (61 × 61 m)
Cost per pole	$400
Utility participation	Stockpile poles
	Provide crews and equipment for pole handling
	Dispose of broken poles
Test benefits	Report of tests
	NDE calibration

important aspect of the problem. Additional information concerning this nationwide full-scale wood pole test program is given in Table 1.

Defining the strength of wood poles through the use of an NDE device can produce other significant benefits.

- Strength evaluation of new wood poles
- More efficient use of wood materials
- Economical wood pole maintenance programs
- Real-time structural reliability assessments of entire transmission and distribution lines

This nationwide wood pole field test program provides an excellent opportunity for utilities to reap significant benefits; those interested should contact the project manager with an estimate of the number and species of poles to be tested. *Project Manager: Phillip Landers*

Transmission Line Mechanical Research Facility

Rapid progress toward full operational status has been made at the Transmission Line Mechanical Research Facility (TLMRF) in the past six months. This facility was designed and constructed by Adelphon, Inc. Design assistance and construction supervision were provided by Ebasco Services, Inc. By January 1983 all major construction tasks were completed (Figure 2).

Activities at the facility have concentrated on shakedown of all the systems and subsystems and on purchase of the shop, yard, and office equipment required by a fully operational facility. All 45 winches, their controllers and brakes, and the numerous data channels used to transmit readings are in place and operational. A total loss of commercial power was simulated, and the data acquisition and control computer continued to function with power from the uninterruptable power supply (battery); the on-site emergency generator was up to full capacity within two minutes, and an operator was able to resume a test that was under way without a hitch.

In February an initial test was performed on a Texas Utilities Co. 345-kV double-circuit tower, and all test elements performed according to expectations. This test tower will remain on the test pad for some time, enabling the staff to apply a variety of load cases, while varying as many equipment operational parameters as possible.

Proof load tests have been conducted on the reaction frames. For these tests the frames were rigged so that 50% of the maximum design load was applied to the frames. The frames and back braces were instrumented to verify the design load paths through the structure. After these tests, the reaction frames and back braces were visually inspected.

A Wisconsin Power and Light Co. 345-kV, single-circuit tower was assembled and a normal series of load cases applied. It was then loaded until failure, which was the first complete research test conducted at the site.

TLMRF has a computer-aided design function, the EPRI Workstation, which contains programs that enable engineers to create and optimize transmission tower designs and view the results on a CRT. During the first quarter of 1983, the EPRI Workstation Version 1 software package and associate 16-bit microcomputer hardware were available for evaluation at a number of utilities. A complement of structural analysis software is included in Version 1, including methods to calculate longitudinal loads from broken conductors, analyze and design pole structures, analyze and design single-pier foundations, and perform finite-element tower analyses. This version of the Workstation software was used extensively in three structural seminars held at TLMRF in February, March, and June and will be used in the remaining structural seminars scheduled for October 11–13, 1983. It is expected that the Workstation software program will enjoy continued rapid progress.

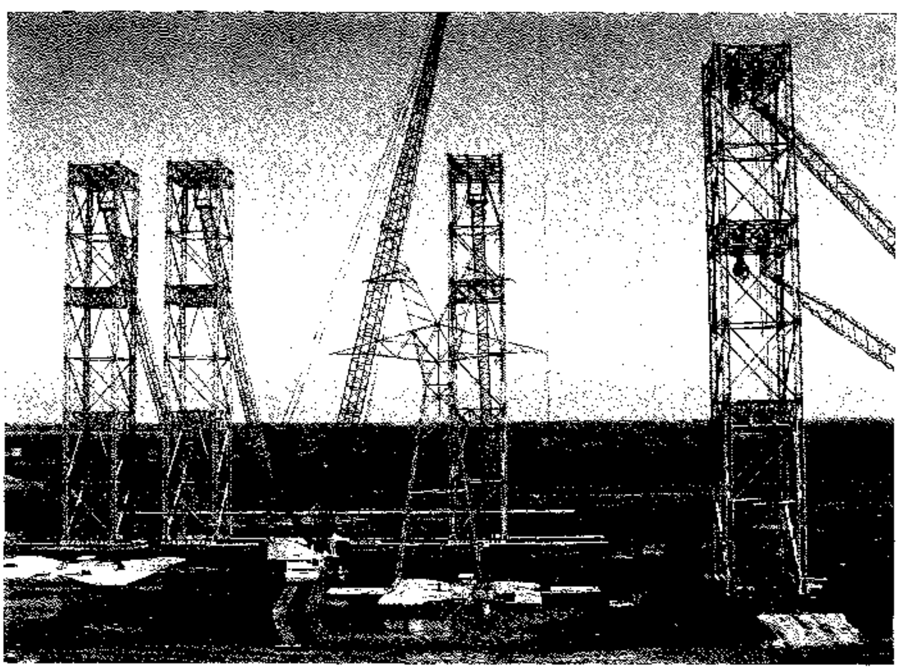


Figure 2 Rigging a tower for testing at the recently completed Transmission Line Mechanical Research Facility in Haslet, Texas. The 180-ft (55-m) reaction towers are capable of applying a 300,000-lbf (134 MN) at the top, and a 200,000-lbf (89 MN) at the 120-ft (37-m) level. An additional 60-ft (18-m) section can be added to the reaction towers, bringing them to a height of 240 ft (73 m).

TLMRF is now ready for full-scale testing to support the EPRI structural research program and the testing needs of electric utilities.

The most popular way for a utility to test at TLMRF will be to cosponsor a research effort on a particular structure of interest. In this mode the utility will supply the tower and a complete set of drawings. EPRI's research contractor will make a thorough computer analysis of the design. Together, the utility engineers and research engineers will design a test series that meets both the utility and research needs. After a review of the pretest and posttest analyses, recommendations will be made for design improvements and/or cost reduction.

This kind of cooperative research effort will reap far greater benefits for the utility than the usual commercial proof test. Perhaps the greatest benefit to most utilities in these times will result from analysis and test of older towers that can be uprated to extend their usefulness. Working with EPRI's contractor, utility engineers will be able to determine the most cost-effective approach to uprating without sacrificing reliability.

According to EPRI's president, Floyd Culler, there is another benefit of cosponsoring structural research that deserves top management attention. In general, it is extremely difficult for an otherwise busy engineer to pick up an EPRI report and learn a new technology. However, if he has had the opportunity to work with our contractors to solve a real problem, he will know and understand the new technology for other applications. Therefore, members of EPRI will multiply the effectiveness of their contribution to EPRI by following up with a cosponsored research effort instead of a typical tower test.

All work at TLMRF will be performed on a cost-recovery basis. EPRI members have already paid their share of capital costs through their dues and will therefore only pay out-of-pocket expenses for tower tests. Nonmembers will be charged both out-of-pocket costs and a pro rata share of capital costs. *Project Manager: Paul Lyons*

DISTRIBUTION

Estimation of cable life

Loss of cable life through aging in the presence of water has been studied under RP-1357, which was completed in 1982. The project consisted of an evaluation of full-size, 15-kV high-molecular-weight polyethylene (HMWPE)–insulated cables aged in the laboratory under accelerated conditions; cables recovered from utilities after field-aging; and supporting materials studies designed to locate matched cable pairs for the aging studies and for the evaluation of aged cables. In one project, Phelps Dodge Cable & Wire Co. studied the electrical properties of the cables (RP1357-1), and in another, the University of Connecticut, Institute of Materials Science (IMS), studied the physical, chemical, and mechanical properties of the insulation (RP1357-3). The cable-aging studies were reviewed in earlier *EPRI Journal* articles (May 1981, p. 41, and June 1980, p. 55), while the early materials studies involving gel permeation chromatography (GPC) were reviewed in the June 1980 article. This current article covers additional results from the IMS studies.

The techniques investigated to characterize the aging of field and laboratory cables included differential scanning calorimetry (DSC), oxidation induction time (OIT), dynamic mechanical tests, differential rheometry, and C-13 nuclear magnetic residence (along with GPC). Changes in properties were observed in field-aged and laboratory-aged cables by employing rheometry, GPC, DSC, and OIT; the changes in some cases for laboratory-accelerated aged cables were somewhat different quantitatively in comparison with field-aged cables. Based on the limited samples evaluated, it was concluded that laboratory-aging of HMWPE-insulated cables under the accelerated conditions produced somewhat different changes in the polymer than did field-aging.

A further significant conclusion is that the scatter of test data increases with aging time, implying nonhomogeneous changes in the insulation during aging.

This project represents the initial attempt to apply these techniques to the cable insulation area and demonstrated that some techniques will be of value, while others will not. *Project Manager: Bruce Bernstein*

Improved methods for distribution loss evaluation

Every electric utility planning engineer has had to deal with the problem of assigning a value to distribution losses. Although there is a great deal of published material on the subject, there is no consistent and easy-to-use method to determine the cost of distribution losses. Therefore, arriving at such a number is a time-consuming and difficult task.

With the cost of a generation plant up tenfold in the past 20 years and the cost of fuel increasing at an annual rate of 25% during the past 7 years, the proper evaluation of the cost of losses has never been more important. Correct economic treatment of losses can result in large savings in fuel costs and plant investment.

In a project begun in October 1979, Westinghouse developed improved methods for distribution loss evaluation (RP1522-1). The project sought to improve present loss evaluation methods and develop new methods where possible; perform field tests to verify these methods; and perform a sensitivity analysis of the key parameters (inflation, load growth, and load factor). The contractor was to implement and demonstrate the methods and software on a host utility system.

An additional objective was to prepare a procedures handbook to be used by distribution engineers in the application of the method and computer program developed in this project.

In the development and testing of the models and software, Westinghouse was assisted by Salt River Project (Arizona). The entire service area of the Salt River Project was used to conduct comparison tests. The rigorous loss evaluation method employed was a combination of measurements, statistics, and distribution facilities data to model the system.

The resultant loss evaluation method was independently evaluated by the Public Service Electric and Gas Co. (PSE&G), New Jersey, to confirm that the method was suitable for utilities operating in a vastly different environment than that of the Salt River Project. The loss evaluation method has been restructured as a computer program, called SCALE (simplified calculation of loss equations). It consists of five major models: economics, primary and lateral line losses, substation and distribution transformer losses, distribution power losses, and distribution area losses. The design of SCALE enables utilities not only to evaluate present system losses but also to examine future systems and policies under varying criteria.

One of the interesting findings of this project (one that the distribution engineer can immediately identify with) is that more than 50% of all energy losses in a distribution system (from the high side of the substation to the load) are incurred in distribution transformers. This suggests that utilities should think twice about changing out pole-mounted distribution transformers that are currently overloaded. Of course, a high load factor may dictate a change, but if not, it may be wise to weigh the penalty of a moderate increase in I^2R losses against the increased core loss that would be incurred by a change out to a larger transformer. *Project Manager: T. J. Kendrew*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

RISK ASSESSMENT OF TOXICS ASSOCIATED WITH COAL COMBUSTION

Legislative and administrative actions at both the federal and state levels in recent years have reflected an increasing concern over the potential chronic health risks of industrial emissions of toxic pollutants. The electric utility industry is currently subject to pollutant regulations for surface water discharges developed under the Clean Water Act of 1977 and state legislation. It is also affected by the regulation of groundwater contamination under the Resource Conservation and Recovery Act of 1976, the Safe Drinking Water Act, and various state laws. Section 112 of the Clean Air Act, which regulates toxic emissions into the atmosphere, could affect the operation of some coal-fired power plants. The implementation of such regulations requires that they be based on an analysis of the risks associated with toxic emissions; in some cases, emissions control costs must also be considered. EPRI is sponsoring studies by the Rand Corp. (RP1826) and Battelle, Pacific Northwest Laboratories (RP2070) to develop an integrated methodology for assessing these risks and costs, with special emphasis on surface water and groundwater. Also, Arthur D. Little, Inc., has developed a framework for assessing the risks of toxic atmospheric emissions (RP1946), and Purdue University is applying the framework to radionuclide emissions from coal-fired power plants.

The risk–cost benefit assessment methodology is designed to compare the chronic health risks and direct control costs associated with different emission levels of a toxic substance. These different levels may be based on alternative regulatory limits, pollution control systems, or plant designs. In applying the methodology to a specific problem, for each alternative the user specifies plant emissions of the toxic pollutant, determines plant pollution control costs, and uses the risk assessment framework and procedures to estimate the chronic health risk of emissions to the surrounding population.

The framework is designed to help utilities identify issues of importance in siting decisions, in technical design evaluations, and in the license and permit process. The framework can also be applied in the regulation-setting area to help assess the appropriateness of proposed regulations for the utility industry.

The framework is designed so that alternative models can be easily interchanged, making it possible to determine how the use of a particular model affects the risk assessment. Because pollutants can move back and forth between air, water, groundwater, and soil, the general methodology is capable of dealing with all kinds of emissions and with transfers across media. Thus stack emissions and plant dusts, discharges and runoff to surface waters, and leaching from plant coal piles and treatment or disposal facilities may be included in the estimation of source discharges.

For each alternative plant configuration or control system, it is necessary to specify the control costs associated with the toxic emissions under consideration. Only direct control costs are being used in the current EPRI studies, but costs could be expanded to include monitoring and enforcement expenses, as well as the indirect costs of changes in plant efficiency and the price of electricity. Toxic pollutant control problems and processes are relatively new in the utility industry. As a result, information on the costs and effectiveness of control schemes for most pollutants is limited and fragmentary.

Framework stages

The risk assessment framework is divided into five distinct stages that cover source emissions, environmental transport, exposure calculation, population description, and dose-response modeling. To assess the risk associated with a set of emissions, the framework uses a combination of models and measured data at each stage of the analysis.

Source emissions are measured or specified for each alternative. The results serve as input to the environmental transport models, which use plant- and region-specific parameters to estimate toxic pollutant concentrations in the air, surface water, soil, and groundwater around the power plant. The concentrations and other information describing the region can then be used to determine exposure rates from inhalation, ingestion of contaminated water and food, and, if appropriate, dermal contact. The population surrounding the plant can be specified both by group and by location. Population group distinctions are based on known differences in health risk or exposure conditions. For example, if children are particularly susceptible to exposure to a specific toxic, special consideration is warranted for this group. Finally, literature sources are used to provide information on dose-response relationships for all chronic health effects associated with the pollutant. This dose-response information is combined with the exposure and population information to calculate the risks associated with both background pollution levels and the plant emission levels.

Within this basic framework, the environmental transport modeling covers transport and dispersion, physical and chemical transformations, degradation and decay, transfer between media, and biological uptake. The modeling approach is to select the most appropriate individual models for each medium (air, surface water, overland transport, and soil/groundwater) and then to couple the inputs and outputs of these models together to account for intermedia pollutant transfers. The EPRI studies have included extensive reviews of the modeling literature to determine the categories, characteristics, and usefulness of available models.

As an aid in defining a problem or the appropriate focus of an analysis, the studies are developing simplified procedures for making preliminary calculations of environmental concentrations and transfer rates. With these procedures and a thorough sensitivity analysis, one can determine which types of emissions and environmental pathways can safely be ignored, and which must be investigated with more complex environmental models and additional data collection. Software has been developed for the simplified procedures, and it will be transferred to utilities through workshops (jointly sponsored with the industry's trade associations) and through TEAM—UP, a software service for utilities maintained by EPRI at Battelle, Columbus Laboratories.

Quantitative risk assessment for toxic pollutants must deal with the problem of uncertainty. For many pollutants, model inputs and parameters will frequently be inaccurate or unavailable. Moreover, models used in the different analytic stages will vary in accuracy. The current EPRI studies have investigated various possible approaches for dealing with these uncertainties and estimating how they propagate through the series of models. The approach found to be the most suitable combines extreme-value and sensitivity analysis at all stages of the risk calculations.

Case studies

The use of the framework is being illustrated in a series of case studies. Two of the studies involve surface water and groundwater transport. They are based on hypothetical 500-MW(e) coal-fired power plants in Washington and Nebraska. For the hypothetical Washington site, the analysis is considering plant arsenic emissions and the potential exposures through surface water and groundwater. The risk calculations are based on drinking water consumption in the region around the plant. For the hypothetical Nebraska site, the analysis is investigating the environmental concentrations and possible human exposures associated with selenium emissions from the plant. For both sites, the direct costs of alternative methods of controlling pollutant emissions will be estimated and reported, along with the associated chronic health risks.

In each of these studies, it is assumed that power plant discharges—that is, the combined ash pond effluent and coal pile runoff—flow directly into an adjacent river. Groundwater contamination arises through leaching from coal piles and from ash treatment and disposal sites. Both kinds of emissions are traced through the environment by using a combination of the simplified and the more complex models. In this way the case studies can demonstrate how the user might apply models at either level of complexity to surface water and groundwater pollution problems. The pollutant concentrations derived from the environmental modeling are compared with normal background levels in the region, and population exposure rates are calculated on the basis of average consumption rates for drinking water and other products. These exposure rates are used with dose-response models and descriptions of the local population to calculate the net health risks.

Other case studies have illustrated the use of the framework for atmospheric emissions of toxics. Variables in these case studies included boiler type (tangentially fired or cyclone), plant size (100 to 1600 MW [e]), and coal type and source. Geographic characteristics were represented by combined meteorological data and combined population data for different sites. Two toxics were considered: arsenic derived from coal (after accounting for the amount of arsenic remaining in the bottom ash and the amount removed by control devices) and benzo[a]-pyrene released in the gaseous phase during coal combustion.

Another case study is under way to illustrate the use of the framework for radionuclide emissions from coal-fired power plants. This case study necessitated the modification of an atmospheric transport model to consider radioactive decay.

Framework application and extension

The objective of this work is to develop a flexible, integrated risk—cost benefit assessment methodology for toxic pollutants to be applied by utility analysts, researchers, and policy analysts. More work is needed over the next year to tailor the methodology to the requirements of utilities. Users at varying levels of sophistication, employing internal computer capability and, if necessary, external support, should be able to apply this approach to a variety of toxic emission problems. The methodology is well suited to assess the risks and costs associated with alternative levels of regulation, such as water quality standards. By determining the risks and costs of alternative control systems or plant sites for a number of pollutants, it could also be useful in making technology choice and siting decisions in the utility industry.

EPRI plans to extend the framework to consider other sources of toxics in addition to coal combustion. Risk assessment projects will be initiated in the near future to consider PCB issues and alternative biofouling control practices. *Project Managers: Ronald Wyzga, Paolo Ricci, and Abraham Silvers*

EFFECTS OF ACIDIC DEPOSITION ON AGRICULTURAL CROPS

The effects of acidic deposition on agricultural crops are under study at four sites: the Boyce Thompson Institute for Plant Research at Ithaca, New York (RP1812), Argonne National Laboratory near Chicago (RP1908-1), Oak Ridge National Laboratory at Oak Ridge, Tennessee (RP1908-2), and North Carolina State University at Raleigh (RP1908-2). At each site field crops important to the region are exposed only to simulated acidic precipitation, while similar control plots receive the normal ambient precipitation. The simulated acidic rain is applied in amounts similar to those of ambient rainfall; different levels of acidity are being investigated, ranging up to 10 times the acidity of ambient rain. In addition to these field studies, laboratory experiments are being conducted to investigate the interaction of acidic rain with crops.

At the Boyce Thompson Institute, researchers are studying the direct effects of acidic precipitation on crops and are also attempting to quantify the dry deposition of particulate matter on plant surfaces.

Radishes were selected for investigation because they are reported to be among the most susceptible crops to reduced yield from acidic rain. The response of radish plants to simulated acidic rain was studied in three separate four-week greenhouse experiments. The variety, cultural conditions, and application of simulated rain were standardized, but other conditions (light, temperature) were allowed to vary among tests. The effects of acidic rain were investigated in two ways: plants grown in soil were compared with those grown in artificial mix; plants whose soil absorbed the simulated rain were compared with those whose pots were covered to prevent absorption by soil.

The results of the different tests showed many similarities: the dose-response functions were similar; with increasing acidity, reductions in mass were greater for below-ground tissues than for shoots; and the acidity that produced statistically significant reductions in yield was at least twice that of current rainfall in eastern North America.

Despite the many similarities, some differences in the test results were found, differences regarding the rate of growth and the final biomass of plants; the ratio of below-ground-tissue mass to shoot mass; and the magnitude of reductions in growth and yield associated with the most acidic rain treatments (pH 3.0 and 2.6). Although the soil medium and the covering of pots also affected growth and yield, these factors did not have important effects on how the plants responded to simulated acidic rain. It appears, therefore, that the actual mechanism of plant damage by acidic precipitation is similar for different environmental conditions.

Although radishes are reported to be particularly susceptible to acidic rain damage and greenhouse radish plants are generally more susceptible than field-grown plants, reductions in the yield of greenhouse-grown plants resulted only at rates of acidic deposition greater than those now occurring in ambient rain. Further, these results were obtained over a range of environmental conditions and with two different soil media. Researchers are attempting to verify these results in field experiments in which simulated rain is being applied to a variety of crops.

Quantifying the effect of dry-deposited material continues to be a significant problem in assessing the effects of acidic deposition. Experiments at the Boyce Thompson Institute have used simulated rain to study the removal of uranine particles (sodium fluorescein; mean diameter, 0.08 μm) from plants. Soybean plants (a pubescent variety) were exposed to about 1.5×10^4 particles per cm^3 for six hours in a closed chamber. The plants were then subjected to 1 cm of simulated rain for 60 min, and the throughfall was collected every 30 s. The concentration of uranine in each fraction was measured, as well as the total amount of uranine left on the plants after exposure to rain.

About 40% of the total particulate deposit was removed by the one-hour exposure to rain. In this time the pattern of removal showed three phases. During the first phase (about 3 min), the rate of removal increased very rapidly to a maximum and about 10% of the deposit was removed. During the second phase (about 20 min), the rate of removal declined to about 20% of the maximum and an additional 20% of the deposit was removed. During the third phase (about 30–35 min), the rate of removal declined more gradually and an additional 10% of the deposit was removed. Because uranine is a very water-soluble compound, this kind of removal pattern is probably determined by the wetting of foliage and the flow and mixing of water on its surface. At first, water builds up on the leaves; then it is displaced by, and mixes with, incident precipitation. The particulate material remaining is probably resident on surfaces that are not affected by rain—for example, the underside of leaves.

At Argonne National Laboratory, a facility called MARS (microcosms for acid rain studies) has been designed as the principal research tool for acidic deposition investigations. The facility is a large outdoor lysimeter complex with 46 fiberglass microcosms, each 8 ft long by 4 ft wide by 4.5 ft deep (2.4 by 1.2 by 1.4 m). These microcosms are embedded in the ground—in an excavation with drainage—and filled with soil. Forty microcosms are arranged in pairs beneath a steel framework that supports clear polyethylene sheeting for excluding ambient rain (Figure 1). Six microcosms are located outside the shelter.

Two soils are being used in the current MARS experiments, Alvin and LaHogue. These two were chosen because of their importance in the Midwest and their contrasting characteristics; in addition, they are among the soils thought most likely to be affected by acidic deposition. Three horizons of the Alvin soil were arranged in some microcosms and two horizons of LaHogue in others, according to core samples from the location in Illinois where the soils were obtained. Ceramic samplers were placed at various depths for extracting soil water and groundwater. Sensors for measuring soil temperature and moisture levels were placed with the water samplers in order to follow the flux of incoming water through the soil column.

Although both soils are thought to be potentially sensitive to acidic deposition, measurements of pH, cation exchange capacity, and neutralization potential suggest that the Alvin soil is more sensitive than the LaHogue. Although the soils' sulfur levels were similar, the Alvin soil has a much higher sulfate absorption capacity and thus may be less susceptible to cation leaching from sulfate mobility. Comparisons of the two soils should help in deciding what characteristics are most important in estimating soil sensitivity.

The microcosms were planted with a grass-legume mixture typical of a pasture or hay

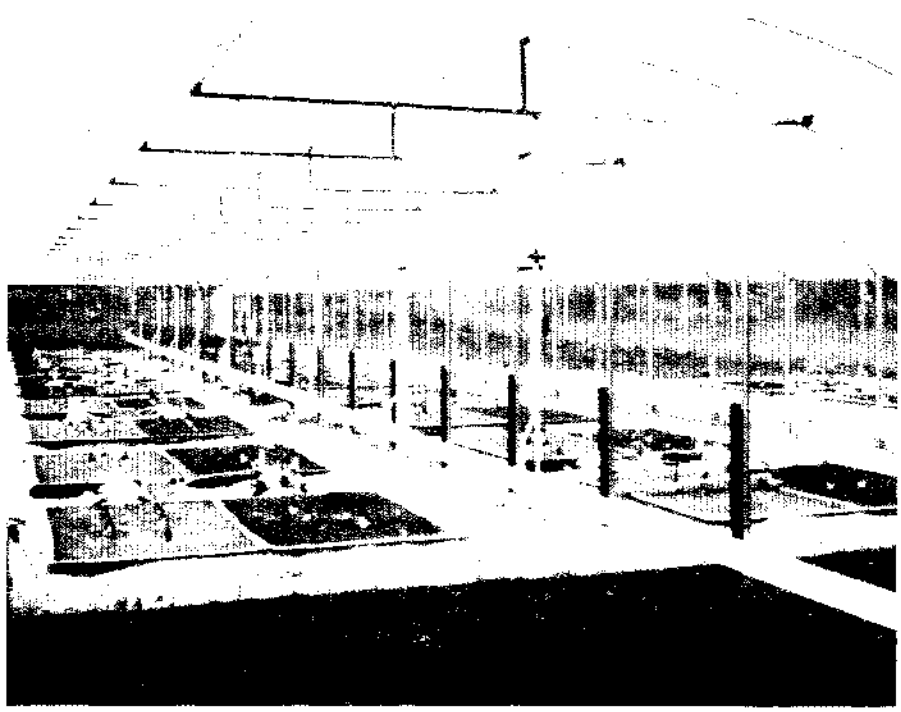


Figure 1 In this sheltered facility at Argonne National Laboratory, agricultural crops planted in microcosms are being exposed to simulated acidic precipitation. The fiberglass microcosms are arranged in pairs and filled with one of two soils under investigation.

crop. The crop will be harvested several times a year, but because it is a perennial, long-term cumulative effects can be assessed. Six different treatments of simulated rain are being sprayed on the plots in a replicated block design. Treatment chemistries are based on data from the National Atmospheric Deposition Program network's north-central region; the acidity level ranges from no strong acids to 10 times the NADP acidity. Unsheltered plots receiving ambient rain are also being examined.

Research objectives are to assess the short- and long-term effects of acidic precipitation on the productivity of the two plant-soil systems. Plant growth, yield quantity and quality, and photosynthesis rates will be measured to determine effects on vegetative productivity. Because it is hypothesized that acidic rain may deplete soil nutrients through leaching, mass balance calculations based on input (precipitation) and output (harvested crops and groundwater) will be made to determine nutrient budgets and carbon, sulfur, and nitrogen cycling in the systems. The mobility of heavy metals will also be studied. Soil microbial activity is being measured to investigate the impact of acidic rain on microbial processes important to plant growth and nutrient cycling.

Chemical analyses of the soil and soil water before the experimental treatments began revealed no significant differences among microcosms of the same soil type. After five simulated rain events in the fall of 1982 (with a total deposition of 2.3 cm), there were no significant differences in groundwater quality among the treatments. Rain simulations are continuing because any effects are expected to be subtle and measurable only in the long term, if at all.

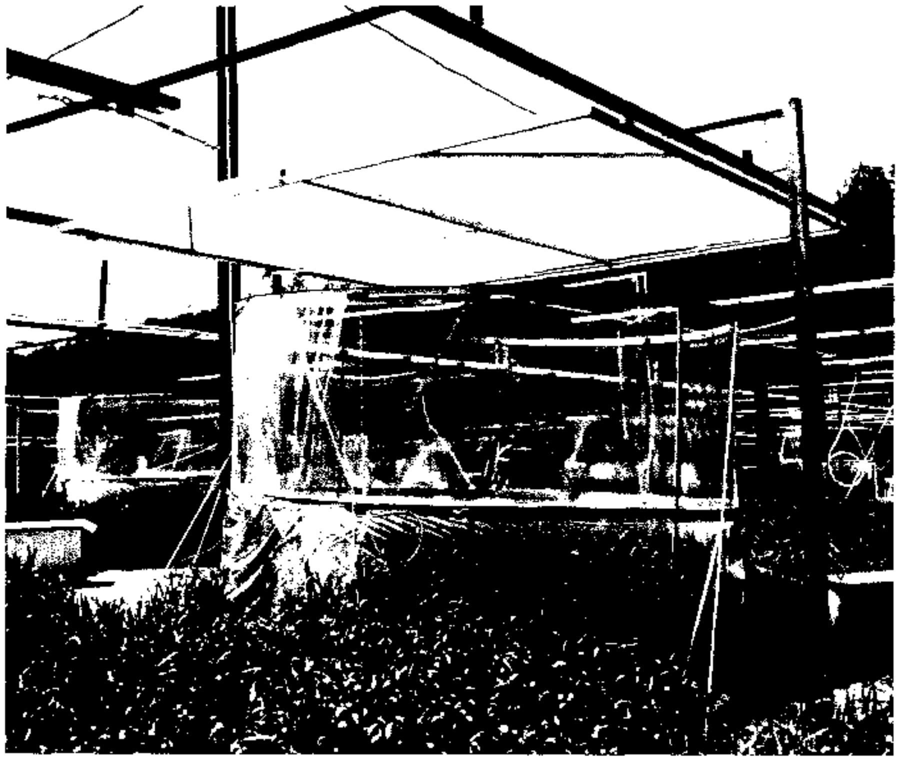
Greenhouse studies are being performed to provide supporting data for the field experiments. Preliminary studies of radish plants have indicated that compensatory processes may occur in plants damaged by extreme acidic exposures. Higher photosynthesis rates were measured for leaves on plants treated with simulated rain of pH 2.6. The total photosynthetic fixation of carbon dioxide per plant was reduced for these treatments, however, because of a decrease in total leaf area. Dose-response studies of greenhouse-grown plants have indicated that plants may not always respond negatively to acidic rain exposure.

At Oak Ridge National Laboratory, greenhouse-grown soybean plants were exposed to simulated acidic rain (pH 2.6 to 5.6) and gaseous air pollutants (sulfur dioxide and ozone) to determine how short-term physiological processes are integrated into a whole-plant response. Injury to growing leaves, characterized by marginal necrosis and leaf deformation, was induced by exposure to simulated rain of pH 2.6 and, to a lesser extent, pH 3.4. Growth inhibition resulted only from exposure to the rain with a pH of 2.6, and there were no significant pH–air pollution interactions. Growth analyses of plants from periodic harvests indicated that the inhibitory effects of pH 2.6 rain were mediated through a reduction in leaf area. This reduction was not attributable to a decreased allocation of nutrients to leaves, but rather to leaf deformation. A second experiment confirmed that simulated rain with a pH of $\geq$3.4 did not inhibit plant growth. Cumulative water use, a measure that integrates aspects of root size, leaf area, and physiology, was remarkably similar in plants exposed to simulated rain with pH values of 3.4, 4.2, and 5.6. These experiments suggest that the vegetative growth of soybeans may be adversely affected by acidic rain only if the pH is low enough to cause physical damage to leaves and the loss of photosynthetic area.

In field studies at Oak Ridge and at North Carolina State University at Raleigh, soybean seedlings were exposed to ambient rain (average pH of 4.2) or to simulated rain with the pH adjusted to 5.2, 4.2, or 3.2. The plants, which were grown in special field chambers (Figure 2), were also exposed to either charcoal-filtered or nonfiltered air. Growth reduction due to ambient gaseous pollutants (primarily ozone) ranged from 10 to 14%. The differences in growth between plants exposed to ambient rain and plants exposed to simulated rain with a pH of 4.2 were small (<5%), indicating that the rain simulation system adequately mimics the effects of natural rain at approximately equal levels of acidity. On the basis of average foliage biomass, it was determined that plants exposed to rain with a pH of 5.2 grew best and those exposed to pH 3.2 rain grew least. The growth of plants exposed to charcoal-filtered air exceeded the growth of those exposed to ambient air for each pH value.

At this time, we have little indication that acidic deposition is adversely affecting crops in the United States. However, there is some tentative indication that ozone in the presence of acidic deposition may exert some additive detrimental effect. Work in progress will quantify the nature and extent of this interaction. *Project Manager: John Huckabee*

Figure 2 At Oak Ridge National Laboratory, field chambers like this are being used for acidic precipitation research. (The experimental crop shown here is winter wheat.) Covers shelter the plants from ambient rainfall.



R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

SOLAR DOMESTIC HOT WATER SYSTEMS

An EPRI program to determine the operating characteristics and performance of residential solar heating, cooling, and hot water systems that use electric load management equipment was initiated in 1975 (RP549). The program's third phase, now complete, emphasized field testing of experimental systems. As part of this research, test data were collected from solar water-heating units installed at demonstration sites in Albuquerque, New Mexico, and on Long Island, New York. The major objectives of the water heater test program were to demonstrate the technology, obtain field data, develop an understanding of energy storage dynamics relative to power demand and electricity consumption, validate portions of the EMPSS (EPRI methodology for preferred solar systems) computer program, and use the validated models to simulate other hot water systems.

Under RP549 solar and load-managed domestic hot water (DHW) and space-conditioning options were investigated. Phase 1 of the program addressed system definition and is documented in ER-467-SY and ER-594; Phase 2, detailed system design, is described in ER-1206-SY. In Phase 3 local contractors were engaged to build houses incorporating experimental solar equipment, and data were collected, analyzed, and used for model validation. Final reports are now in preparation.

EPRI's research on solar DHW systems complements work by DOE and various electric utilities. DOE has sponsored laboratory tests of generic types of solar DHW systems (one tank, two tank, and thermosyphon) through the National Bureau of Standards. The Tennessee Valley Authority (TVA) has conducted standardized laboratory tests of complete solar DHW systems offered by manufacturers. Both DOE and TVA have also conducted field demonstration projects. In addition, over 200 solar DHW demonstration projects have been sponsored by individual utilities.

EPRI's program has extended the field testing of solar DHW systems, focusing on utility and customer issues and incorporating more comprehensive system design, instrumentation, and monitoring efforts. Field demonstrations were conducted at two occupied residences in Albuquerque and a third on Long Island.

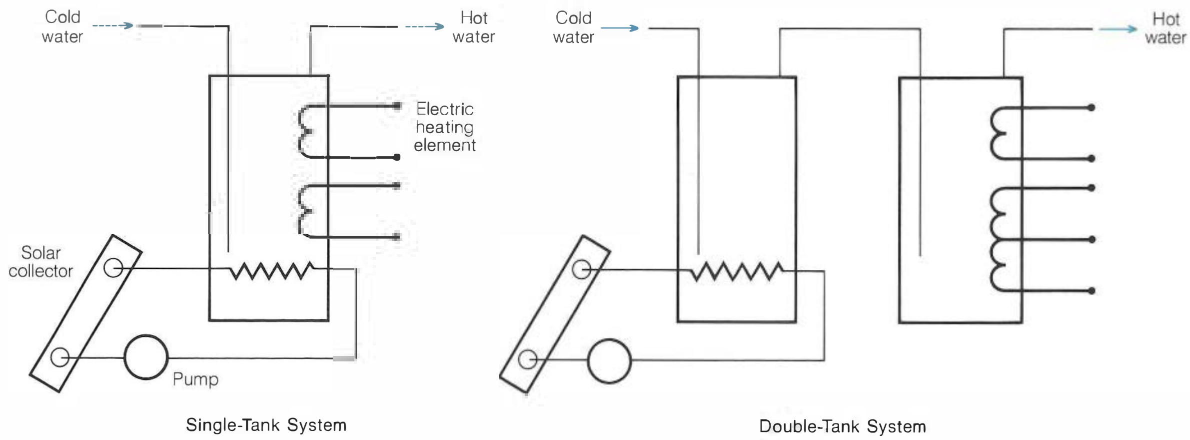


Figure 1 EPRI has sponsored field demonstrations of these two types of load-managed solar water heaters. The single-tank system uses the same tank to store solar energy and to heat water by electric resistance for load management. The double-tank system uses separate tanks for these functions.

Field test program

The solar DHW system tests, which began in late 1979, were conducted over two winters and one summer. They were specifically designed to support analysis of four questions important to utilities.

- What reduction in peak electricity demand would solar DHW systems achieve in comparison with conventional equipment?
- What changes in off-peak load and what savings in total electricity consumption would solar systems achieve?
- What storage capacity would be needed to meet the water-heating requirements of the occupants?
- How efficiently would stored energy be used?

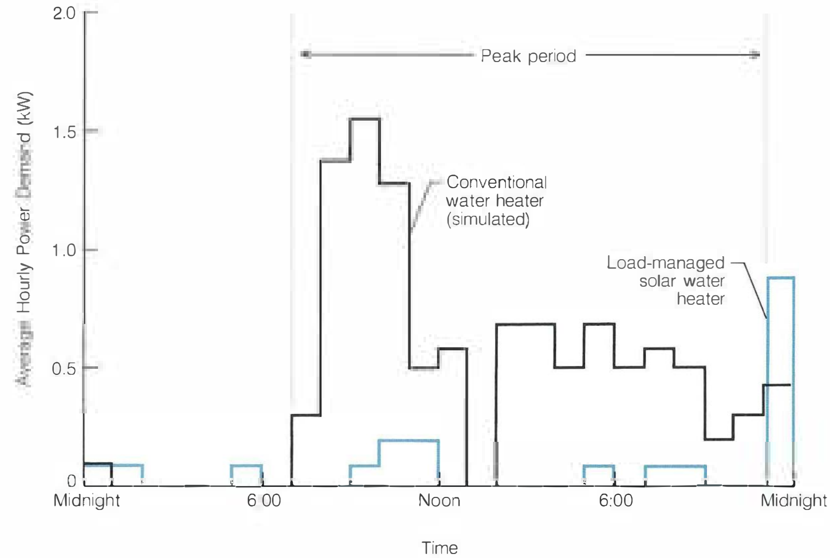
The DHW system installed in the Long Island home and one of the systems at Albuquerque used two hot water storage tanks—one for solar energy storage and one, containing water heated by electric resistance during off-peak hours, for load management. The other Albuquerque system used only one tank for both solar storage and load management (Figure 1). All three systems were electric-pump-driven systems of the indirect, antifreeze-loop type, in which the liquid used to collect solar energy contains an antifreeze solution and is separated from potable hot water by a copper heat exchanger. Single- and double-tank antifreeze-loop-type systems are the most common electric-pump-driven solar DHW systems. Thermosyphon systems were not tested.

Comparisons between the measured performance of the load-managed solar water heaters and the simulated performance of a conventional water heater showed that both the single- and double-tank solar designs achieved very high reductions in peak period electricity consumption (nearly 100% in some cases). A sample power profile illustrating such savings is presented in Figure 2. The peak savings were primarily attributable to load management; other factors strongly affecting the reductions were the home's water consumption profile, the number of solar system storage tanks, and the seasonal variation in solar radiation.

A simple mathematical model was derived from the data to relate peak electricity consumption (as a percentage of total electricity consumed) to load-managed storage capacity (as a percentage of daily water use). This model will be useful for estimating the performance of one- and two-tank load-managed solar systems.

Comparisons with the simulated performance of a conventional water heater also showed that the load-managed solar DHW systems reduced total monthly electricity consumption by as much as 90%. For all the test systems, the portion of the total thermal load (including tank losses) supplied by solar energy—a fraction called the solar contribution—correlated well with the solar-load ratio, which compares the total solar radiation incident on the collectors with the amount of energy needed to meet the hot water thermal load (Figure 3). The correlation between the solar contribution and the solar-load ratio shows that when incident solar energy exceeds thermal load, single-tank solar water heaters are able to utilize solar energy for a greater portion of the water-heating requirement than double-tank heaters; the two types of system use solar and electric energy in about the same proportions when thermal load exceeds incident solar energy. This correlation was derived from measurements at geographic locations as diverse as Albuquerque and Long Island and should be useful in making future performance estimates for similar situations.

Figure 2 The power profile of an 80-gal single-tank load-managed solar water heater at EPRI's Albuquerque demonstration site was compared with the simulated profile of a 52-gal conventional water heater for an average weekday in June 1980. The solar system was effective in shifting electric load from the peak to the off-peak period.



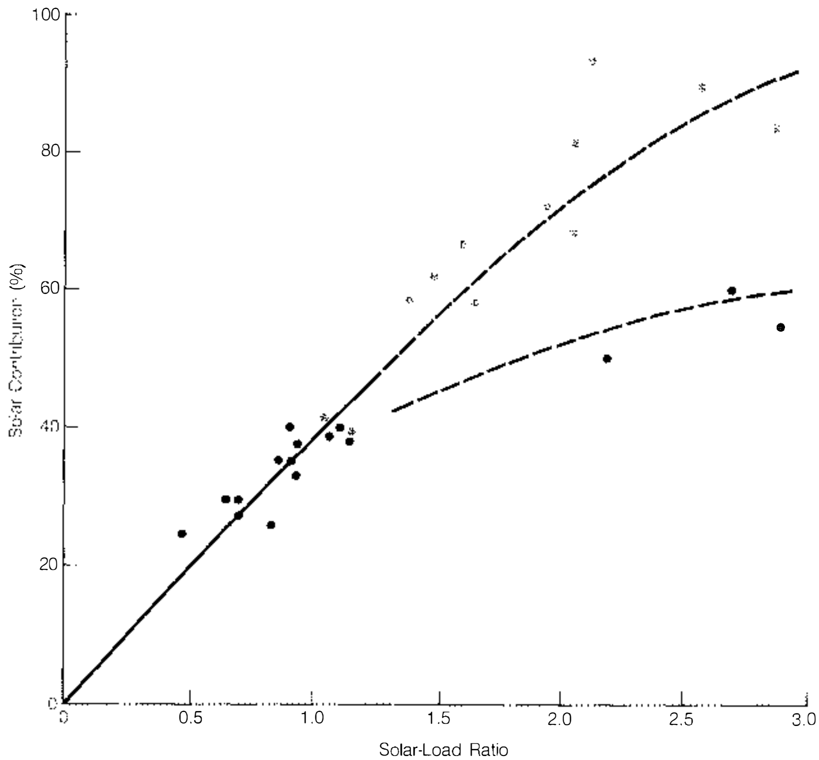
Average solar collection efficiencies at the test sites ranged from 40% to 50% and were consistent with manufacturers' specifications. Storage losses appeared to be 30% higher for the double-tank systems than for the single-tank system. Standby heat losses were difficult to quantify accurately but ranged from 2 to 6 kWh a day, depending on system design and water consumption. The single-tank system occupied about the same amount of house space as a conventional system, and the double-tank systems about twice as much; both types were relatively easy to install and were generally reliable. Few problems occurred with the load management equipment, and overall reliability improved over the course of the testing program.

Model validation and simulations

The test data collected at these demonstration sites provided the basis for validating the EMPSS DHW system model. The original EMPSS program was developed between 1975 and 1978 by Arthur D. Little to assess technical and economic trade-offs for alternative residential space-conditioning and DHW systems. The newest version of the program (designated 2.1) incorporates the validated solar DHW model.

In this study the EMPSS water heater model was adapted to reflect the actual hard-

Figure 3 Test data for single-tank (color) and double-tank (black) solar water heaters show the correlation between solar contribution (the portion of thermal load met by solar energy) and solar-load ratio (the ratio of total incident solar radiation to hot water thermal load).



ware configurations tested in Albuquerque and Long Island. Simulation models for both single- and double-tank load-managed solar water heaters were validated, first on a component basis and then on a system basis. EMPSS predictions of solar collection efficiency agreed closely with the experimental data. The simulation models for both the single- and double-tank systems predicted daily and hourly average electricity consumption patterns that matched well with those observed. Because double-tank systems are easier to model (since the solar collection and load management functions are carried out in different tanks), better agreement was obtained for these systems than for the single-tank system.

After validation, simulations were performed for several solar DHW systems (load-managed and non-load-managed single- and double-tank systems) and for a conventional system with and without load management. The EMPSS simulations tested the sensitivity of electricity consumption, demand, and solar energy collection to important system design parameters. The program's unique modeling capability allows thermal stratification in storage tanks to be simulated in terms of a moving interface between the hot and cold regions of the stored water.

For an average March day on Long Island, all the simulated solar and load-managed solar systems significantly reduced peak electricity consumption when compared with a conventional electric water heater without load management (Table 1). Because of their lower storage tank standby heat losses, the single-tank systems were more effective in reducing total electricity consumption than the double-tank systems. The load-managed double-tank system was the most effective solar system in displacing peak electricity consumption because of its larger storage volume and was the only one to outperform the conventional water heater with load management in terms of peak period savings.

Table 1
SIMULATED ELECTRICITY USE FOR SIX WATER HEATER DESIGNS

System	Average Daily Electricity Use (kWh) Peak Period	Total
Conventional	18.4	21.7
Load-managed conventional	2.1	21.4
Single-tank solar	8.9	11.3
Load-managed single-tank solar	5.8	11.1
Double-tank solar	10.4	13.1
Load-managed double-tank solar	1.2	13.9

Note: Based on Long Island weather conditions, March 7–18, 1981.

Some solar system parameters had very little influence on the total amount of electricity consumed. These included heat loss from insulated collector piping, liquid flow rate, heat exchanger effectiveness, thermostat deadband, and collector tilt angle. The addition of load management did not reduce the solar contribution for the double-tank system and only slightly reduced it for the single-tank system.

Future research

The selection of an appropriate water-heating system (i.e., the system with the lowest life-cycle costs) for an application requires consideration of the hot water consumption profile; climate; the costs of purchasing, installing, and maintaining the equipment; and the cost of electricity service. EPRI's solar DHW testing and simulation program has demonstrated that solar water heaters can effectively combine electricity savings with management of electric loads. The EMPSS water heater model can enable utilities to identify preferred systems on the basis of the above factors.

Solar DHW systems are characterized by high initial costs, and at their present price level the market for them has largely been saturated. Technical design improvements have maintained the systems' market position for several years, but no immediate opportunities for large performance gains are in sight. Moreover, consumer tax credits have provided a disincentive to manufacturer-sponsored R&D directed toward cost reduction, and as these tax credits are reduced or phased out, the market may decrease significantly. To improve the economics of solar DHW systems, R&D is needed to reduce initial system costs. A Canadian utility, Ontario Hydro, is now doing research in this area (Canada has no tax credits for solar DHW systems), but little has been done in this country. Although current priorities and funding levels preclude EPRI from undertaking similar activity, this could be a high priority in future solar DHW research. *Project Manager: Gary Purcell*

CHEMICAL ENERGY CONVERSION

*The current focus of EPRI's chemical energy conversion subprogram is the development and demonstration of advanced electrolyzers for producing hydrogen from water and electricity. On the basis of earlier technoeconomic assessments, which also covered thermochemical and hybrid processes for water splitting, it was determined that the advanced water electrolysis technology offered near-term benefits to the electric utility industry for such applications as generator cooling. For the longer term, the demonstration of advanced electrolyzers could establish a technology base for the utilization of hydrogen as an energy carrier by electric utilities and their customers. The results of the hydrogen production process assessments, as well as the initial efforts in electrolyzer development, are described in previous R&D status reports (*EPRI Journal, *March 1981, p. 55, and May 1982, p. 52). A technical brief, "On-Site Production of Electrolytic Hydrogen for Generator Cooling," is also available.*

General Electric Co. and Teledyne Energy Systems have designed, developed, and tested advanced prototype electrolyzers under RP1086-5 and RP1086-6, respectively. The electrolysis module design and development work was essentially funded by EPRI in both cases; the manufacturers shared the cost of system design, engineering, and fabrication. The specifications developed for the electrolyzers were based on a survey of hydrogen usage for generator cooling by some 30 power plants and on the recommendations of a utility advisory group. System reliability, ease of operation, scheduled maintenance of one week once a year, fail-safe and unattended operation, and modular construction with truck-transportable units were emphasized in the critical component design requirements. The important system performance criteria are as follows.

- Hydrogen capacity: 100–500 standard ft³/h (2.8–14 m³/h)
- Dew point: −40°F (−40°C) at atmospheric pressure
- Hydrogen delivery pressure and temperature: 100 psig (689 kPa); 115°F (46°C)
- Hydrogen purity: minimum of 99.95 vol% hydrogen; maximum of 0.05 vol% oxygen, 0.1 ppm water, 0.2 ppm hydrocarbons, 0.4 ppm halogens, and 50 ppm total impurities
- Electricity consumption: <17 kWh per 100 standard ft³ (2.8 m³) of hydrogen at rated capacity

General Electric electrolyzer installation at PSE&G

This system is based on General Electric's solid-polymer-electrolyte electrolysis technology for large-scale hydrogen generation, a technology developed under the earlier sponsorship of DOE, Niagara Mohawk Power Corp., Empire State Electric Energy Research Corp., and the Gas Research Institute. During the course of the EPRI-funded design program, it was determined that for this high-reliability, small-capacity application, the electrolysis module should use smaller cells with an active area of 1 ft² (0.09 m²) rather than the larger, 2.5 ft² (0.23-m²) cells developed under the DOE program. The final design of a module using 1-ft² cells and having a hydrogen production capacity of 200 standard ft³/h (5.7 m³/h; 20 kW equivalent) was completed in early 1980. Through a utility solicitation, Public Service Electric and Gas Co. (PSE&G) was selected to host a demonstration of this unit at its Sewaren (New Jersey) power station.

A three-phase factory validation and test program—consisting of initial checkout and parametric testing of the electrolysis module and the system components, acceptance tests, and system confirmation tests—was carried out under the joint sponsorship of EPRI and PSE&G for about six months. During the acceptance tests the system was operated by Sewaren plant personnel to simulate plant conditions.

At rated conditions of 1000 A/ft² and 28.6 V (dc), the output of the 14-cell stack was 191 standard ft³/h (5.3 m³/h) of hydrogen at 100 psig (689 kPa) with a dew point of −45°F (−43°C). The gas sample analysis indicated a hydrogen purity of over 99.99 vol% and less than 10 ppm of total impurities. The system passed leakage tests at 100 psig and responded to all appropriate automatic shutdown conditions. After the prototype system passed the acceptance tests in September 1981, testing continued for four more months to a total of 2400 hours under simulated full-load, cycling, and part-load conditions.

Figure 4 shows the system as installed at the Sewaren plant, where it provides hydrogen to four 110-MW electric generators. At Sewaren 100-psig (689-kPa) hydrogen from the electrolyzer is compressed to 1250 psig (8.6 MPa) for storage in cylinders, then let down to 30 psig (207 kPa) to meet generator cooling demand. After the installation of the electrolyzer, a power supply unit, a hydrogen dryer, and a facility compressor was completed in November 1982, initial checkout activities and operator training began.

Problems with the facility compressor developed after 300 hours of operation and have prevented sustained operation of the electrolyzer. An alternative approach that bypasses the compressor and uses direct hydrogen injection is being implemented. In the meantime, the plant personnel are operating the electrolyzer and venting hydrogen to collect data and gain operating experience. Because of the early compressor problems and the malfunction of some of the electronic controls, electrolyzer operation was limited to 300 hours in the first four months. During April–May 1983, however, 600 hours were logged without the compressor.

The evaluation plan was suspended during this initial period and is rescheduled to start as soon as the changes enabling direct hy-

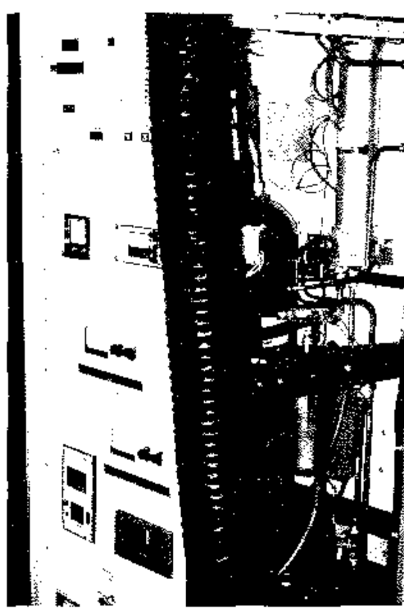


Figure 4 Prototype electrolyzer installation at Public Service Electric and Gas Co.'s Sewaren power station. Developed by General Electric Co. for the on-site supply of hydrogen for generator cooling, this unit contains an electrolysis module based on solid-polymer-electrolyte technology.

drogen injection are made. The objectives of the two-year evaluation are to verify design specifications, reliability, and availability; determine installation and operating and maintenance costs; identify design improvements; and compare costs for electrolytic and purchased hydrogen. PSE&G will prepare a final report after the evaluation is completed.

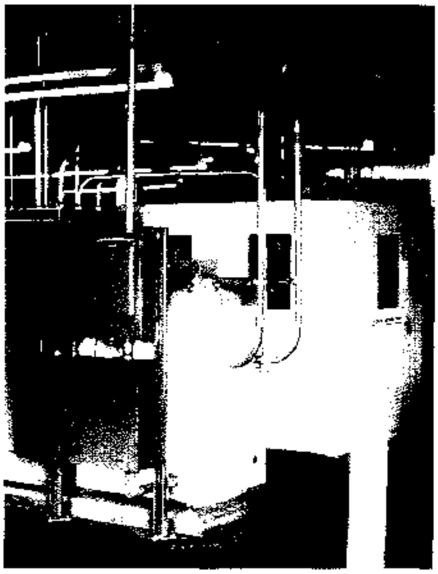
Teledyne electrolyzer installation at Allegheny Power

This system is based on a bipolar, filter-press-type electrolysis module that uses an alkaline (potassium hydroxide) electrolyte. Teledyne had earlier tested a proprietary cathode catalyst as part of a component research effort supported by DOE. Under the EPRI program an advanced electrolysis module was designed that includes the proprietary catalytic cathodes and achieves better flow and temperature distribution across the cells. In this module the electrolyte is pumped over both electrodes and is controlled to low levels of differential pressure across a cell. The new cell components and cell frame designs were confirmed in partial (10-cell) stacks and in a full (98-cell) stack with a hydrogen capacity of 500 standard ft³/h (14 m³/h).

Allegheny Power System, Inc. (APS), was selected to host a demonstration of the 500-ft³/h hydrogen generator at its Pleasants (West Virginia) power station. The prototype unit was factory-tested in phases similar to those described for the PSE&G unit. After about 2000 hours of operational and acceptance testing, the unit was delivered to the Pleasants station in August 1982 to begin a two-year evaluation program.

The installation at Pleasants is shown in Figure 5. Two 600-MW generators are supplied with hydrogen at 60 psig (414 kPa) from on-site storage (2200 psig; 15.2 MPa) or from the electrolyzer. Unlike PSE&G's installation at Sewaren, the Pleasants operation uses hydrogen directly from the electrolyzer without compressing it to storage pressure. For the first three months the unit experienced differential control instability and other control problems that caused frequent automatic shutdowns. These early startup problems, together with a lack of experience in operating and troubleshooting the unit, limited the system's availability to less than 75%. However, minor field repairs of controls and an increased technical understanding of the process controls and instrumentation by the operators improved the availability to 90% during the last two months.

Figure 5 Prototype electrolyzer installation at the Pleasants power station of Allegheny Power System. The advanced electrolysis module in this unit, which was designed by Teledyne Energy Systems, is based on potassium hydroxide electrolyte.



In the initial four months (September–December 1982), the unit logged 1780 hours; it operated for an additional 3200 hours during January–May 1983. Unfortunately, most of this testing has been performed at a small fraction of the unit's rated capacity. The turbine generators at Pleasants are only three years old and hence have low leakage rates. Hydrogen demand is typically less than 10% of electrolyzer capacity. In order to better utilize the unit, the APS staff is considering the installation of a compressor to fill the on-site storage cylinders.

Expanded applications of electrolytic hydrogen

A study is currently assessing the potential of industrial electrolytic hydrogen in the northeastern United States (RP1086-13). On-site electrolyzers installed by industrial customers could mean increased kWh sales and better utilization of baseload plants. Three utilities and two major hydrogen gas suppliers are participating in this study. The results of the assessment will be available in August 1983.

Another area of interest involves the stress corrosion problems being experienced in boiling water reactors (BWRs). Many of these problems result from the presence of a very small amount of dissolved oxygen in the reactor water. A recent 30-day experiment at Commonwealth Edison Co.'s Dresden-2 plant investigated the addition of hydrogen to reactor water to combine with the traces of dissolved oxygen. The results confirmed that this hydrogen water chemistry technique is a potential cure for BWR stress corrosion problems (*EPRI Journal*, January/February 1983, p. 52).

The feasibility and cost-effectiveness of providing hydrogen for BWR plants from on-site electrolyzers are being evaluated by EPRI's Nuclear Power Division (RP1930-2). Also, Commonwealth Edison is planning to demonstrate hydrogen water chemistry at Dresden-2 for a full 18-month fuel cycle in 1983–1984, and it is considering the use of on-site electrolyzer(s) to provide part of the expected hydrogen demand of about 100,000 standard ft³/d (2832 m³/d). The operating and maintenance data from the PSE&G and APS prototype electrolyzers will be studied to evaluate the potential application of such units in BWR nuclear plants; thus the electrolyzer demonstration effort is being closely coordinated with activities by the Nuclear Power Division, Commonwealth Edison, and the electrolyzer manufacturers. *Project Manager: B. R. Mehta*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

NDE CENTER OPERATIONS

The Nondestructive Evaluation (NDE) Center, constructed and operated for EPRI by J. A. Jones Applied Research Co., is the first and only facility of its kind in the United States. At its location in Charlotte, North Carolina, the center is the site of important technology transfer from evaluated and qualified research results to field testing in the power plant environment. Dedicated to fulfilling the specialized NDE equipment and training needs of the electric utility industry, the 67,000-ft² (6200 m²) center has been in operation since its completion in February 1981 (Figure 1). This status report summarizes significant progress in the center's work during 1982.

Management, technical, and training activities are carried out in seven specific task areas: project coordination and management, steam generator inspection, BWR stainless steel pipe inspection, steam turbine inspection, heavy section inspection, technical support, and training and human resources development.

The NDE Center staff, which currently numbers 60, is organized into six principal areas: the center management, quality assurance, inspection applications and technology, BWR repair applications, technology field applications, and administrative support. During 1982 the center added several positions, including a heavy section inspection manager and technical support staff in other task areas.

Project coordination and management

A project control system (PCS) describes center projects and measures their progress. The PCS defines manageable segments of work (work activities), the phased completion of which allows project goals to be achieved and reported at regular intervals. In 1982 the PCS was implemented for the first full year, and all work was executed according to PCS format-developed schedules and approved by EPRI at the start of the year.

Facility activation has been a continuing process since the center opened. A large immersion tank and a crane to facilitate heavy section inspection were added to one laboratory. The instrument calibration and characterization laboratory was equipped and in full operation by midyear to characterize in detail the performance of all ultrasonic inspection system elements. The NDE Center training course uses a third laboratory, which has been furnished with a variety of appropriate power plant component samples. An audiovisual laboratory was also equipped to produce training and technology videotapes.

The center provides EPRI with several types of reports, including monthly reports, monthly highlights, two types of annual reports, and a series of specific technical reports, which are subsequently published by EPRI.

Steam generator inspection

Steam generator inspection emphasizes technology transfer of selected EPRI and Steam Generator Owners Group (SGOG) project results. Among the EPRI research projects are the Battelle, Pacific Northwest Laboratories' multifrequency-multiparameter eddy-current system and the Colorado State University 2D finite-element code for analytic modeling of eddy-current inspection in steam generator tubing. Initial evaluation of the eddy-current system has been completed. The 2D finite-element code was running on the center's VAX computer by the end of 1981.

EPRI has also developed eddy-current signal processing to establish tube plugging limits in once-through steam generator units. Errors in the measurement of the depth of defects near the broached support plate were established by multiparameter, signal subtraction, and adaptive learning network methods. The results of this comparative evaluation have been provided to the cooperating utility.

Among the SGOG projects were two that dealt with problems in certain recirculating steam generator units. The first project evaluated the optimized eddy-current inspection methods for detection of intergranular attack in steam generator tubing. The second project qualified improved eddy-current probes for inspecting small-radius U bends. Evaluation of the optical dent profilometry system was also conducted. Results were compared with commercially available mechanical strain gage and eddy-current methods. Preliminary evaluation of a variable reluctance probe was initiated with the field acquisition of data from a model boiler.

Rapid-response activities continued throughout the year. Primary activities included consultation on eddy-current test data for the McGuire, Zion, TMI-1, Sequoyah, Millstone, and Ginna plants. A major rapid-response activity included the participation

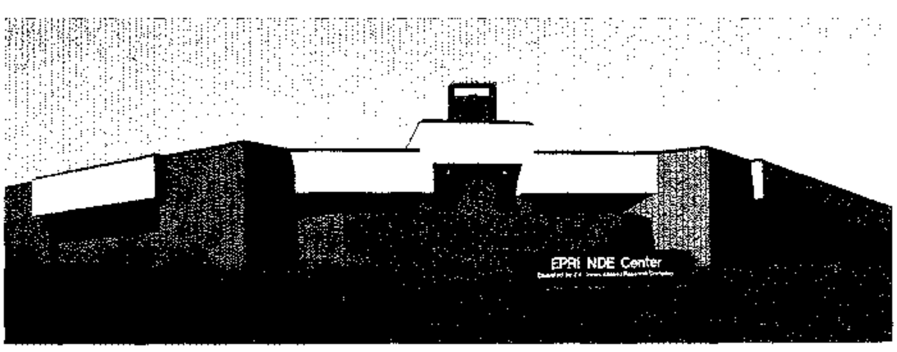


Figure 1 The EPRI NDE Center is housed in this facility in the University Research Park, Charlotte, North Carolina. The 67,000-ft² (6200 m²) facility contains offices, laboratories, machine shop, and high-bay facilities that contain full-size power plant component mock-ups.

of staff members in third-party review teams for Ginna and TMI-1 plant problems.

Steam generator inspection work has been enhanced by the variety of equipment and test samples the center has acquired, which is representative of most R&D and commercial systems. Both portable and fixed-site mock-ups are available for technology testing and qualification. The number of tube samples has also been expanded (Figure 2).

During the last quarter of 1982 EPRI, SGOG, and NDE Center personnel developed a detailed plan for the inspection work during 1983–1985, which combines input from the EPRI and SGOG projects.

BWR stainless steel pipe inspection

BWR pipe inspection emphasizes the transfer of technology developed by EPRI, flaw sample documentation and management, and rapid-response support. The three technology candidates are manual pipe inspection systems, fully automatic pipe weld inspection equipment, and machinery to prepare the weld joint for inspection by modifying surface conditions.

Two systems now used at the center for manual inspection are the Manual Analog Call-Confirmer and the ALN 4060, a newly developed instrument that is operator trainable. Both systems were being evaluated at the end of 1982.

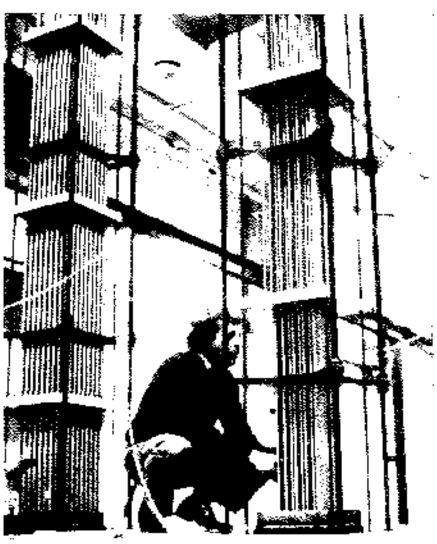


Figure 2 The steam generator mock-up permits testing of tube inspection equipment under conditions simulating the field environment. Shown are two groups of tubes; one represents the steam generators made by Combustion Engineering, Inc., while the other represents the Westinghouse Electric Corp. product. A third set, representative of the Babcock & Wilcox Co. generators, is also available.

Evaluation of the automatic pipe inspection system (APIS) in 1981 indicated that further system development was justified. APIS was combined with a more advanced scanner called AMAPS. The center received this revised system late in 1982.

The center has also carried out an extensive effort to collect ultrasonic data uniformly. A format for ultrasonic data recording has been established in a revised report *(Specification for Digital Report of Ultrasonic Signals).* A review group is studying the physical principles that may be associated with the discrimination powers of certain ultrasonic testing signals. A report of the group's findings has been received.

The center has received and evaluated two types of weld crown contouring equipment. These devices are now undergoing field trials at an actual operating plant, both having been briefly field-tested during 1982.

A major activity in the BWR pipe inspection task area has been to provide the industry with a mechanism for complying with NRC's IE Bulletin 82-03, Rev. 1. This bulletin requires utilities to demonstrate their capability for effectively inspecting BWR piping for integranular stress corrosion cracking.

The center was managing close to 100 pipe samples at the start of 1982. In addition, the center obtained a number of cracked pipe samples that were removed from the Nine Mile Point-1 plant. These samples had been at the hot cell at Battelle, Columbus Laboratories, but they were transferred to the NDE Center in the first quarter of 1983.

Steam turbine inspection

The steam turbine inspection and evaluation methods and the equipment developed under previous EPRI contracts have not been thoroughly assessed, nor have they received widespread field use. More complete verification of these systems will increase their credibility and speed field application. The NDE Center's role in these developments is to evaluate and qualify equipment and methods and to train personnel. Equipment evaluations will include field trials to measure equipment performance adequately under conditions actually encountered in operating power plants.

Three utilities interested in purchasing a state-of-the-art turbine rotor evaluation system provided funding, which, with the EPRI base support, allowed the center to evaluate the system's ability to repeat performance (Figure 3). The evaluation of the unit's performance near the rotor bore has been documented and compared with the optimum expected from a commercial system's performance on the same flaws (NP-2640).

The SAFER code for rotor lifetime prediction was acquired and run on the center's VAX 11/750 computer late in 1981. During that time the first debugging was done in cooperation with two utilities that had acquired the same code. SAFER accuracy was verified during 1982. The center organized an informal SAFER users group and provided all participants with the corrections identified during verification. The center also held a workshop to further inform users of the code's status and to allow hands-on experience with its analysis capability.

During the year the NDE Center obtained another fossil fuel turbine rotor and 22 shrunk-on disks from nuclear plants to add to the 6 rotor samples acquired earlier. These components represent the products of most of the major suppliers and compose the most comprehensive rotor test sample set in the industry.

The center staff responded rapidly to several turbine-related problems in 1982. Of particular interest was the help to Carolina Power & Light Co. in obtaining better information on steam turbine disk fracture toughness.

Heavy section inspection

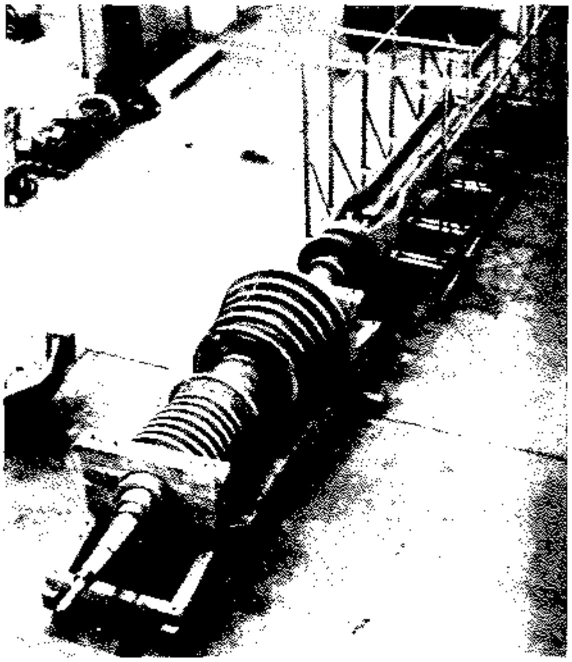
The center's heavy section inspection emphasizes transfer of the radiographic and acoustic imaging technologies to the industry, rapid response to utility needs, and interface with national and international pressure vessel inspection programs. The center received the 3-MeV miniature linear accelerator X-ray source (Minac) and a manipulator for pump inspection in July 1981. Inspection system refinements continued and additional field applications supported in 1982.

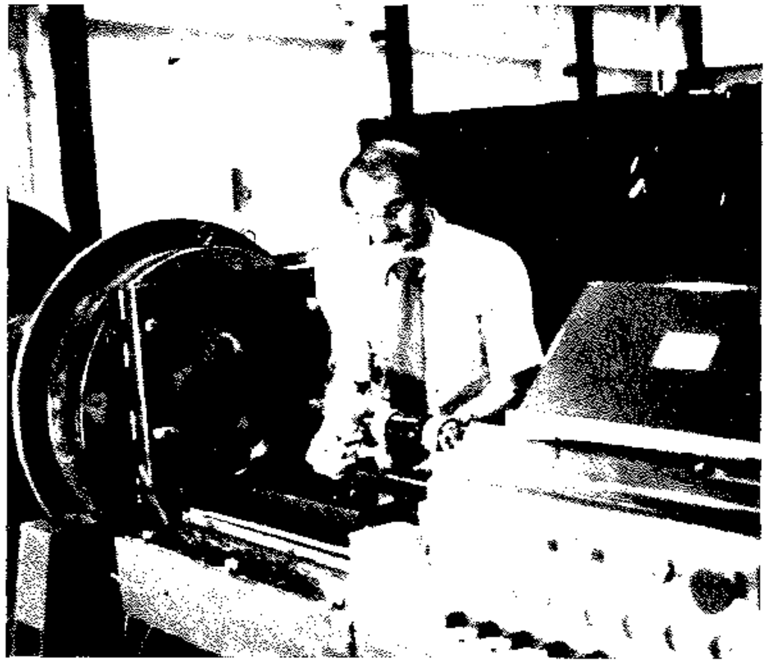
The NDE Center organized activities that allowed a utility and its selected in-service inspection (ISI) vendor to demonstrate the effectiveness of a near-surface (underclad) ultrasonic inspection system in one of the ISI vendor's facilities. The center completed parallel work by year-end that will make possible future qualifications of this nature.

Major 1982 work on pressure vessel imaging system (PVIS) elements took place in the EPRI R&D contractor's shop. This system is designed to provide acoustic images of flaws found in pressure vessel welds. In November NDE Center and EPRI staff members worked with an ISI vendor to simulate the system's first field trial (Figure 4). Center facility modifications were completed by year-end in anticipation of the 1983 PVIS qualification work.

EPRI has continued to acquire heavy section samples during this reporting year, including several near-surface flaw samples that contained cracks under a variety of clad configurations. These samples were added

Figure 3 The NDE Center has completed an evaluation of an advanced inspection system for steam turbine rotors owned by American Electric Power Co., Inc. This system, called TREES (left), was compared with conventional technology represented by the BUCS system (right). The results, which show superior performance by TREES, are contained in NP-2640.





to the center's existing full-section retired component samples.

A second international round-robin test series for pressure vessels is currently under way. The NDE Center hosted the U.S. activities of the program for the inspection of steel components (PISC II). A number of ISI vendor teams came to the center to examine two large nozzle blocks, which are a part of the sample inventory for this program.

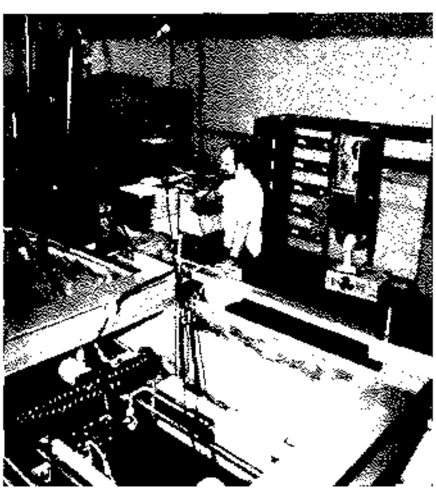


Figure 4 Demonstration and documentation of inspection system performance against realistic flaw conditions is a major effort of the NDE Center. This photo shows the demonstration of a device used to detect flaws in a pressure vessel.

Technical support

The work carried out at the center requires a support infrastructure. One technical support area is computer applications. During 1982 the center enhanced the VAX 11/750 computer system hardware capabilities. VAX now has 2 million bytes of main memory, 248 million bytes of on-line disk storage, and an accelerator for floating point instructions. Considerable software capability was also added during the year. The center purchased, installed, and debugged software packages for general mathematics and statistics, graphic display subroutines, and signal processing. Center staff generated a variety of specialized software. In addition, two laboratory computers were purchased and brought on-line for specialized applications.

During 1982 the NDE Center completed activation of the laboratory for ultrasonic instrument performance checks. The facility is capable of characterizing the individual ultrasonic system's pulser, transducer and cable, and receiver. The laboratory was used to document transducer and ultrasonic equipment performance for the PISC-II round-robin testing. EPRI has distributed a Technical Brief to announce the laboratory's capabilities of reproducing tests in response to NRC's Regulatory Guide 1.150 on reactor vessel ultrasonic inspection.

The center completed a review of available steam generator problem data that may result in near-term component change out. The data collection did result in the organization and provision of a workshop on steam generator repair/replacement in November. The workshop proceedings will be published in 1983.

Training and human resources development

The NDE Center charter does not allow center staff to routinely inspect power plants. To prepare others to perform these examinations with developing technology, the center keeps interested individuals up to date on developments and subsequently provides operator training when technologies are ready for field use. In addition, the center provides specific training material on more basic NDE methods. These activities are one of the key steps in technology transfer.

The center offers technology workshops, in-service inspection team training, and basic skills training. Technology workshops show participants developing technologies before they are ready for routine field application. The ISI team training provides operator training in new technologies ready for field application. This training method is a joint effort of the training and technical staffs. The basic skills training is developed and offered as a part of the training task. Typical offerings are provided in response to needs identified by the utility community.

ISI team training was first provided in 1981 to support Minac use for a reactor coolant pump inspection at the Point Beach nuclear plant. In 1982 training was developed and provided for utility personnel who supervise this inspection operation. In addition, a refresher course for operators who have previously used the system was provided for one application.

In 1981 the center began to develop training courses in visual examination of inservice nuclear plants. A first-level course was offered at the end of 1981 and six times during 1982. In addition, several utilities used the materials for in-house training at their plants. More than 500 people, representing over 50 utilities, as well as inspection contractors, NRC participants, and R&D contractors, took this course series and participated in the technology workshops. Approximately 400 of these individuals came to the center; the remainder trained at specific utility plant sites with materials developed by the center.

As part of its human resources development program, the center helps academic institutions promote the NDE career field. Work in this area has resulted in a cooperative program in which a university professor and a utility representative spent several weeks at the center to develop a senior-level NDE survey course, which is now being made available to other universities.

The NDE Center has provided the utility industry with improved, field-ready NDE equipment and procedures; critically needed documentation on present inspection methods; mechanisms for demonstrating the effectiveness of current techniques; rapid aid for critical, short-term problems; and specific training for generic industry needs. *Project Manager: Gary J. Dau*

COMMON CAUSE FAILURES

Common cause failures (CCFs) are generally considered to be events involving multiple hardware failures that have some common cause or origin. CCFs are of continuing importance because of their potential impact on plant safety and availability. However, such multiple failures are comparatively rare. This fact, together with confusion over the exact definition of CCFs, has resulted in widely varying estimates of their probability of occurrence. There are also many opinions about how to model CCF phenomena and how to collect meaningful data for use in such analyses. Most important, CCF defensive strategies are difficult to define in light of the current confusion. EPRI is conducting an extensive investigation of the CCF area to resolve these issues (RP2169).

Prescribed preventive maintenance actions, large design margins, and equipment redundancy have long been standard practices to avoid equipment failures in power plant systems. The success achieved through redundancy depends on the degree of independence among system components. An awareness of this has focused attention on the potential for an event in which some factor is responsible for the simultaneous failure of several parts of a system. Such events have come to be called CCFs. It is possible for standard failure avoidance measures (e.g., redundancy) to be the victims of this kind of event or for reliability improvement measures (e.g., preventive maintenance) to be the cause.

The CCF phenomenon is real, if rare. The loss of all the jet engines on a commercial airliner because of bird or hailstone ingestion is one dramatic example. The synchronous nature of such failures is, of course, intimately associated with the cause of failure. The possible causes are numerous, comprise many fundamentally different types with indistinct boundaries, and, along with the events themselves, generally exhibit a perplexing range of characteristics. To successfully account for these events in a reliability analysis in any but the most approximate way will require a careful delineation of their properties. However, there is no consensus on exactly what constitutes a CCF event—and hence much disagreement about the frequency of CCF occurrence, accepted methods of analysis, and systematic engineering practices for achieving defenses.

RP2169 seeks to resolve this confusion and disagreement by developing standard methods for acquiring CCF data and modeling CCF phenomena; it will also investigate defenses against CCFs. In the current phase of the project, the issues of CCF definition and classification are being addressed by Los Alamos Technical Associates.

Initially, the contractor conducted a peer survey and workshop to draw on the expert views of six nuclear plant reliability engineers with special experience in CCF issues. One topic explored was the meaning and use of many common terms, such as *failure, dependency, propagation,* and *cause.* The results revealed that the lack of a generally accepted method of classifying failure events blurs the boundary between CCFs and non-CCFs from the outset. Somewhat unexpected was the group's inability to reach a consensus on the definition of failure. Some consider failure to be a physical impairment, whereas others broaden the definition to include any lack of function for any reason.

It is clear that the events of interest are those involving component unavailability—that is, the inability of a component (black box or equivalent) to perform its intended function. The peer survey showed that it is important to distinguish between two mutually exclusive subsets of unavailability: failure, or the physical impairment idea, and functional unavailability, that is, a lack of intended performance due to the absence of a proper input or support function from some external source.

The peer survey emphasized the overriding need to develop a top-level classification system for equipment unavailability events, including their causes, before tackling the question of which events should be defined as CCFs. Such a system, which requires careful consideration of the proximate cause of component unavailability, has been devised. It defines six mutually exclusive classes of events; any component unavailability event may be placed in only one class. A set of simple symbols has also been devised to enable the event classes to be described quickly and accurately (Figure 5). The six classes are as follows.

- Independent failure: the failure of a single component due to a noncomponent cause (i.e., not the unavailability of another component).
- Cascade failure: the failure of a single component due to the unavailability of another component.
- Functional unavailability: the inability of a single component to perform its function because of the lack of proper input; the proximate cause can be either the unavailability of another component or a noncomponent cause.
- Conditionally independent failures: two or more component failures due to the same noncomponent cause; *conditionally independent* indicates that the multiple failures, while statistically related, are not related to each other in any physical or engineering sense.
- Multiple cascade failures: two or more component failures directly caused by the unavailability of another single component.
- Multiple functional unavailabilities: the inability of two or more components to perform their function because of the lack of proper input; the proximate cause can be either the unavailability of another component or a noncomponent cause.

The viability of the classification system was assessed in a data benchmark test. The central question was the consistency of

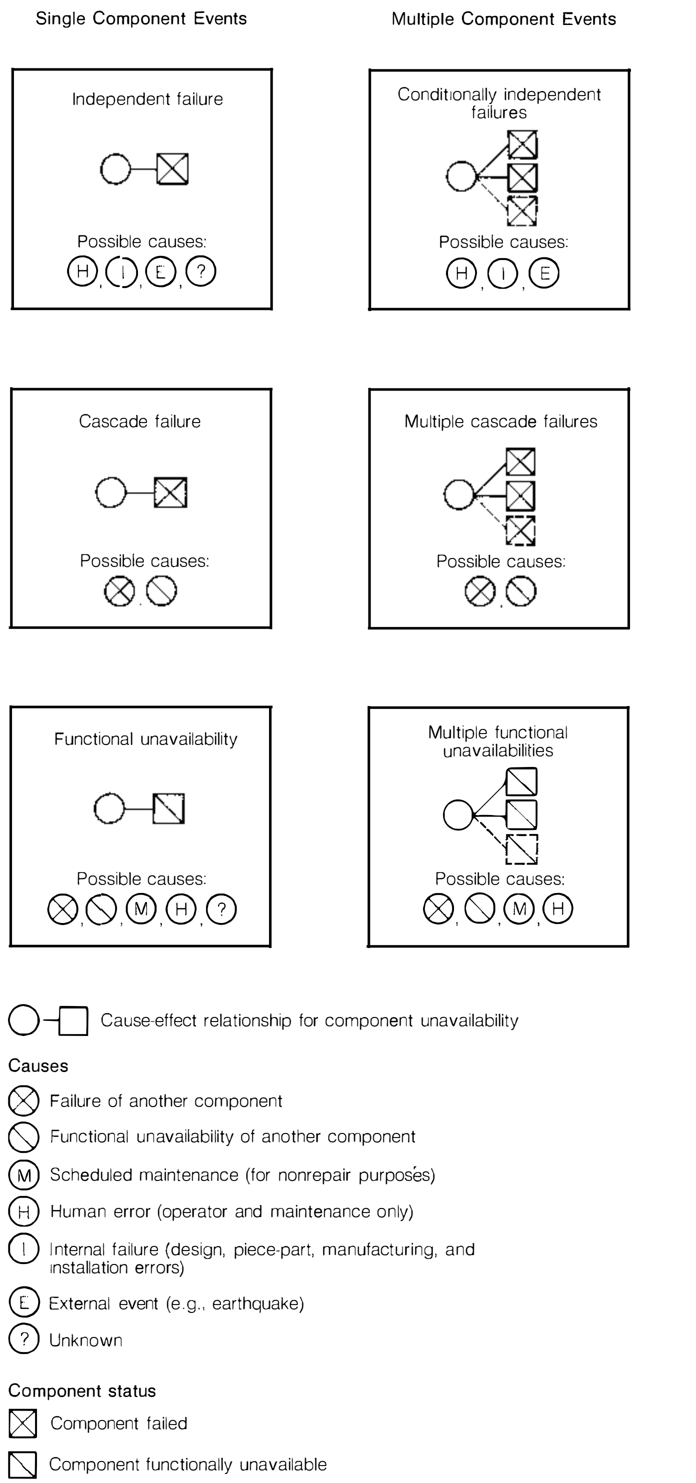


Figure 5 A classification system and a set of symbols have been developed for describing component unavailability events. The six event classes are shown here; three involve the unavailability of a single component, and three the unavailability of multiple (two or more) components. A circle containing the appropriate letter or sign is used to indicate the proximate cause of an event, and a square with the appropriate sign is used to indicate the status of each unavailable component.

event interpretation among several analysts with various backgrounds and experience. Seven participants were provided with a detailed instruction book, forms for recording entries, and a common set of 50 selected events drawn from actual experience records. Their task was to classify each event according to the system described above. A reference or standard solution was developed for each event, and each participant was scored against these references. The average score was 63%, with a high of 88% and a low of 41%. An evaluation of each entry revealed that improvements in the instructions and more emphasis on analyst attention to detail could be expected to yield average scores in the 90% range. These results are quite encouraging for a first-time application. Equally important, the seven participants unanimously agreed that the classification system represented a major step toward clear, consistent event analysis and communication.

Now that a simple classification system for component unavailability events has been developed, together with a straightforward method of symbolic representation, the tools exist to address both data analysis and modeling in a common, specific language. The system provides a new frame of reference for considering how to define CCFs and points to the resolution of problems connected with the use of that term.

Because a CCF, by everyone's definition, deals with multiple component events resulting from a common cause, the CCF issue focuses on the three multiple component classes of the proposed system (Figure 5). Each of these classes does involve a common proximate cause, and one could choose to call them all common cause events. It is not appropriate to label them all common cause failures, however, because that would blur the necessary distinction between failure and functional unavailability.

It seems that the conditionally independent failure class is the one most strictly associated with common cause failures, but this association owes more to semantics than to any clear underlying technical basis. Further, the methods used to model multiple unavailabilities in system analysis, both implicitly and explicitly, address all three multiple component classes to various degrees, as well as the so-called domino situation, in which two or more cascade failures occur in series.

It is apparent that the label CCF is an inadequate descriptor of events that can be more precisely designated by the proposed classification system. It is therefore recommended that the technical community discontinue the use of this simplistic term.

Even as a vague indicator of the general field, the term *dependent events* would be more suitable.

This proposal must now be reviewed by the technical community. It is felt that if it is accepted, a large measure of the current confusion can be put to rest. Moreover, a broad acceptance of the new classification system will facilitate communication and promote clarity in dealing with statistical interpretations, data collection, data analysis, modeling, and reliability issues in general. *Project Manager: David Worledge*

PRESSURE VESSEL DOSIMETRY

During the past two years EPRI has supported the development of an analytic method that is expected to reduce uncertainties in pressure vessel (PV) dosimetry and neutron flux calculations. This method has been validated in a series of benchmark and prototypic PV mock-up experiments, and it is now being applied to the analysis of experiments performed in operating light water reactors (LWRs). The present analysis is expected to identify major sources of uncertainty in LWR radiation fields and result in an easy-to-use computer program package.

The physical properties of materials change when exposed to a field of high-energy neutrons over extended periods of time. In particular, LWR stainless steel PVs are known to become more brittle as a function of exposure. In operating reactors this rate of embrittlement is closely monitored by irradiating samples of the PV material in surveillance capsules at locations subject to a more intense neutron flux, which are called accelerated locations because they are closer to the reactor core.

Because of uncertainties in the rate of shift in material properties and the difficulty of determining the neutron flux of critical PV locations with sufficient accuracy, NRC has raised questions about the ability of some of the older plants to withstand a sudden drop in temperature that would occur under certain accident conditions (pressurized thermal shock). Because of these uncertainties, NRC requires that PV life expectancy be determined by using conservative margins, so there is a considerable incentive to improve the accuracy of methods used for predicting the time integral of the neutron flux or fluence to which the PV is subjected during its operating history.

Neutron flux and fluence can be determined either analytically by calculating neutron transport from the core to (and through) the PV, or experimentally by measuring the activation of foils placed in surveillance capsules or outside the PV in the reactor cavity. Both approaches are subject to intrinsic uncertainties. The transport calculations are sensitive to nuclear data deficiencies and simplifications introduced in modeling the reactor geometry. Methods based on unfolding the neutron flux from foil activation data are limited by experimental uncertainties and by the small number of foil types available to determine the energy dependence or spectrum of the flux. Ideally, if different foil types were sensitive to different energy ranges, the neutron spectrum could be determined by using a sufficient number of foils. However, the actual number of foils used is small, and their ranges of sensitivity overlap considerably. This overlap makes the flux-unfolding problem mathematically ill-defined. Although such a problem may be solved, there is no unique solution, and great care must be exercised to ensure that the initial estimate of the flux and the final solution are realistic.

During the past two years, EPRI has supported the development of an analytic dosimetry methodology expected to improve the accuracy of PV neutron flux and fluence calculations. This methodology is being developed by Oak Ridge National Laboratory (RP1399) and will be incorporated in a system of codes called LEPRICON (for least-squares EPRI constants). LEPRICON provides a formal procedure for combining neutron transport calculation results with foil activation data to obtain improved estimates. The method requires that all uncertainties—those in the transport calculation as well as the experimental ones—be quantified. It then uses a generalized least-squares adjustment procedure to obtain the most probable solution to PV flux within the prespecified uncertainty bands. The recommended approach calculates neutron transport by using the two-dimensional discrete-ordinates transport code DOT-4 with a cross-section library derived from versions 4 and 5 of the National Standard Evaluated Nuclear Data File ENDF/B. Uncertainties are determined by evaluating the effects of modeling approximations and by combining calculation sensitivities with known uncertainties in nuclear data. The fifth version of ENDF/B includes uncertainty information in the form of covariances and cross-correlations. Because of the importance of this information to the LEPRICON approach, a substantial effort was spent on the evaluation of ENDF/B covariances and the development of improved and self-consistent dosimetry cross sections.

The development of the LEPRICON methodology was accompanied by a systematic testing and validation effort. The early stages of this effort consisted of analyzing foil irradiation experiments carried out in simple-geometry benchmark fields, such as the californium-252 fission and the intermediate spectrum neutron field experiments at the National Bureau of Standards. Such experiments were used to reduce the uncertainties in basic nuclear data. The simple experimental configurations involved ensured that the analysis would be free of virtually all other sources of uncertainty.

In the later stages the analysis was extended to a series of prototypic pressure vessel mock-up experiments carried out at the Oak Ridge National Laboratory with NRC funding. These experiments, referred to as the pool critical assembly (PCA) and poolside facility (PSF), are of great interest because they represent more realistic neutron fields. The PV is represented by a series of stainless steel plates, between which activation foils can be placed. Thus, researchers can compare calculations with measured activation rates not only at locations corresponding to the surveillance capsules but also throughout different thicknesses of the PV itself.

Results obtained in the PCA and PSF fields helped demonstrate the soundness of the LEPRICON approach. Uncertainties and deviations between measurements and calculations, originally 20–30%, have been reduced by up to factors of two with the application of the least-squares adjustment procedure.

The LEPRICON method is now undergoing its most critical testing at Arkansas Nuclear One, Unit-1 reactor (ANO-1). Calculations for this reactor are being compared with ex-vessel activation measurements taken by the University of Arkansas (RP772-4) and analyzed by the University of Missouri (RP827-4).

These experiments require identification and evaluation of a new set of uncertainties specific to operating reactors. Such uncertainties are introduced by approximations made in modeling the core and PV geometries, the distribution of neutron sources throughout the core, their dependence on operating history, and other exposure-dependent effects. The impact of these uncertainties on neutron flux calculations must be determined and introduced into the LEPRICON data base. This requirement makes an initial LEPRICON analysis rather difficult and expensive. However, subsequent analyses at ANO-2 and other reactors are expected to show that these uncertainties do not strongly depend on reactor type. If individual utilities can rely on predetermined generic uncertainties and avoid costly sensitivity analyses, their use of LEPRICON will be greatly simplified. *Subprogram Manager: Odelli Ozer*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/EPRI Project Manager
Advanced Power Systems				
RP1348-17	Wind Park Development; Status Survey	5 months	43.2	Strategies Unlimited *E. DeMeo*
RP1897-1	Particulate Emissions From High-Asphaltene-Fuel Flames	15 months	75.0	Massachusetts Institute of Technology *W. Rovesti*
RP1971-10	Tempering Ferritic Steels to Prevent Embrittlement by Using an 83 Pb–17 Li Liquid	28 months	140.0	Colorado School of Mines *K. Billman*
RP1996-4	WTS-4 Wind Turbine Test Program	13 months	490.1	United Technologies Corp. *F. Goodman*
RP2101-5	High-Reliability Gas Turbine Control System Development	21 months	216.6	Salt River Project *A. Dolbec*
Coal Combustion Systems				
RP982-33	Preliminary Engineering and Estimating for 10-MW High-Sulfur Spray Dryer Scrubber Installation at Scholz Plant	4 months	65.0	Bumstead-Woolford Co. *T. Morasky*
RP1260-35	Factors Affecting Biofouling of Condenser Tubes: Research Needs	6 months	29.2	University of Miami *M. Miller*
RP1402-22	Bench-Scale Feasibility Study of SO_2 Sorbent Injection	6 months	49.9	KVB, Inc. *M. McElroy*
RP1895-7	Coal-Water Slurry Test in an Industrial Boiler	8 months	582.0	E. I. du Pont de Nemours & Co. *R. Manfred*
RP2113-3	Management of the Cooling Tower Test Facility Program	39 months	436.6	Battelle, Pacific Northwest Laboratories *J. Bartz*
RP2305-2	Evaluation of Japanese Design, Operation, and Maintenance Practices for Coal-Fired Power Plants	17 months	313.0	Bechtel Group, Inc. *A. Armor*
Electrical Systems				
RP1504-4	Control Improvements: NGH–SSR Damping Scheme	22 months	124.1	Siemens-Allis Inc. *N. Hingorani*
RP2209-1	Equipment for Pole Hole Drilling in Rock	35 months	801.3	Foster-Miller Associates, Inc. *R. Tackaberry*
RP2307-1	Turn Insulation Capability of Large AC Motors	42 months	655.8	Ontario Hydro *D. Sharma*

Number	Title	Duration	Funding ($000)	Contractor/EPRI Project Manager
Energy Analysis and Environment				
RP1216-8	Commercial End-Use Model Software Support	8 months	48.0	Criterion Incorporated *J. Wharton*
RP1313-3	Plant Response to SO_2; A Mechanistic Approach	47 months	903.8	Stanford University *R. Goldstein*
RP1614-2	Evaluation of LMSTM Models	6 months	30.0	Lotus Consulting Group *D. Geraghty*
RP1953-18	Simple Models for Capacity Replacements	8 months	37.3	Economic Applications *D. Fromholzer*
RP1981-14	Publications: Transfer of Fuel Planning and Analysis Research	6 months	30.0	Atlantis, Inc. *J. Platt*
RP2279-1	Utility Sales Forecasting by Using State Space Models; Phase 2	6 months	73.8	Scientific Systems, Inc. *J. Chamberlin*
RP2280-2	Evaluation of the Feasibility of Physical Modeling in Solid-Waste Environmental Studies	15 months	27.7	Clemson University *I. Murarka*
RP2283-1	Groundwater Sampling Methods and Related Field Measurements	18 months	232.2	Residuals Management Technology, Inc. *I. Murarka*
RP2283-2	Groundwater Data Evaluation	17 months	261.2	Tetra Tech, Inc. *I. Murarka*
RP2309-1	Methodology for Evaluating the Costs of Air Quality Modeling Uncertainty	7 months	87.0	Brookhaven National Laboratory *R. Wyzga*
RP2369-10	1983 Fuel Supply Seminars	10 months	150.0	Atlantis, Inc. *H. Mueller*
RP2369-50	Coal Price Sensitivity: Utility Information Needs and Agenda	4 months	67.9	Temple Barker & Sloane, Inc. *J. Platt*
RP2370-2	Long-Range Tracer Experiment: CAPTEX	11 months	650.8	Battelle, Pacific Northwest Laboratories *R. Patterson*
RP2371-2	Effects of SO_2 and O_3 on Crops	34 months	525.7	Pennsylvania State University *J. Huckabee*
RP2371-3	Effects of SO_2 and O_3 on Crops	37 months	548.0	Cornell University *J. Huckabee*
Energy Management and Utilization				
RP226-6	Composite Electrodes for Zinc-Halogen Batteries	2 years	353.0	Stonehart Associates, Inc. *D. Douglas*
RP1090-5	Analysis of Residential Storage Heating and Water Heating Field Test Data	6 months	39.2	United Power Association *V. Rabl*

Number	Title	Duration	Funding ($000)	Contractor/EPRI Project Manager
RP1201-28	End-Use Technology Assessment Guide	9 months	31.1	Decision Focus, Inc. *T. Yau*
RP1464-4	Power Electronic Technology Application	5 months	54.7	General Electric Co. *R. Ferraro*
RP1523-3	Development and Production of a Defective Battery Module Detector for Use in EVs	9 months	44.2	Wyle Laboratories *B. Askew*
RP1745-10	Assessment of Design Considerations and Field Repair Procedures to Mitigate Cavitation Pitting in Hydraulic Turbines	20 months	343.5	Acres American, Inc. *J. Birk*
RP1791-6	Corrosion Rate Testing of Metals in Simulated Compressed-Air Energy Storage Exhaust Gas Environment	19 months	199.8	Encotech, Inc. *R. Schainker*
RP2038-2	Comparative Evaluation: Acoustic Flow Measurement System	23 months	136.9	B. C. Hydro *C. Sullivan*
RP2123-2	Testing and Evaluation: Lead-Acid Battery for Bulk Energy Storage	9 months	206.5	GNB Batteries, Inc. *W. Spindler*
RP2419-2	R&D Planning Workshop: Solar Heating and Cooling	4 months	60.2	Hart, McMurphy & Parks *G. Purcell*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/EPRI Project Manager
RP606-11	Real-Time Ultrasonic Sector Scan Imaging	8 months	96.5	Vintek Inc. *J. Quinn*
RP1021-9	Radiation Damage Model Development	1 year	122.5	University of Virginia *T. Marston*
RP1116-4	BWR Suppression Pool and Safety Relief Valve Clearing Phenomena	6 months	40.4	Nutech Engineers *A. Singh*
RP1377-6	Technology Transfer for TRAC—BWR	10 months	118.8	Science Applications, Inc. *M. Merilo*
RP1544-9	TMI-2: Consulting and Advisory Studies	13 months	79.6	Burns and Roe, Inc. *A. Roberts*
RP1544-11	TMI-2: Consulting and Advisory Studies	1 year	81.4	General Dynamics *A. Roberts*
RP1544-13	TMI-2: Mechanical Component Examination, Phase 2	11 months	189.1	Pentek, Inc. *K. Winkleblack*
RP1572-7	Description of BWR Safety/Relief Valves and Related Tests and Analyses	8 months	47.9	General Electric Co. *A. Singh*
RP1585-3	Evaluation of Nuclear Power Plant Standardization Concepts	3 months	69.9	Bechtel Group, Inc. *R. Nickell*
RP1932-36	NTS Engineering Support	3 months	46.1	Astron Research and Engineering *T. Auble*
RP2062-11	Surveillance of LWR Spent Fuel in Wet Storage	15 months	60.0	Battelle, Pacific Northwest Laboratories *R. Lambert*
RP2079-4	Properties of Recrystallized Alloy 800H and Associated HTGR Steam Generator Design Implications	2 years	233.1	GA Technologies, Inc. *R. Nickell*
RP2121-1	Analysis of In-Pile Heat Transfer Tests	14 months	101.0	Rowe & Associates *M. Merilo*
RP2135-10	Aerosol Support Services	1 year	37.2	H. M. Associates, Ltd. *F. Rahn*
RP2160-3	Thermodynamic Data for Corrosion Modeling	2 years	126.8	San Diego State University Foundation *M. Angwin*
RP2166-3	Heat Stress: Medical Screening and Personal Monitoring of Power Plant Workers	2 years	165.0	Pennsylvania State University *J. O'Brien*
RP2180-7	Flaw Evaluation in Clad Nuclear Pressure Vessels	10 months	109.9	General Electric Co. *D. Norris*
RP2228-2	Zircaloy Corrosion Properties Under LWR Coolant Conditions	39 months	100.0	Atomic Energy of Canada, Ltd. *A. Machiels*
RP2296-2	Millstone-2: Decontamination Evaluation	14 months	57.1	Radiological and Chemical Technology, Inc. *C. Wood*
RP2347-3	BWR Advanced Operator Aid Evaluation	4 months	207.0	Nuclear Software Services *D. Cain*
RP2392-7	NSAC Quality Assurance Development; Pilot Implementation	9 months	36.0	S. Levy, Inc. *T. Auble*
RP2404-2	LOFT Consortium; Planning Reactor Safety Experiments	6 months	25.0	NUS Corp. *R. Oehlberg*
RP2406-1	Spent-Fuel Cask Surface Decontamination	10 months	52.9	Transnuclear, Inc. *L. Martel*
RP2430-3	LMFBR: Seismic Evaluation	2 months	54.8	Bechtel Group, Inc. *D. Gibbs*
RP2430-5	Institutional/Financial Planning for the Design, Construction, and Operation of a Near-Commercial-Scale LMFBR Plant	4 months	50.0	Middle South Services, Inc. *D. Gibbs*

Planning and Evaluation

Number	Title	Duration	Funding ($000)	Contractor/EPRI Project Manager
RP1678-9	Transmission R&D Evaluation	1 year	43.0	Power Technologies, Inc. *G. Applegren*

New Technical Reports

Each issue of the *Journal* includes information on EPRI's recently published reports.

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ADVANCED POWER SYSTEMS

Combustion Turbine Design Guidelines Based on Deposition-Corrosion Considerations

AP-2739 Final Report (RP1345-1), Vol. 1; $14.50

Potential problems with the use of residual oil as a combustion turbine fuel were investigated. Tests were conducted in a pressurized passage under simulated turbine operating conditions to assess these problems and develop operating guidelines for these fuels. This volume presents the results of tests using petroleum residual fuels, specifically oil that was washed to reduce the alkali content and then treated with magnesium. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Arthur Cohn*

Evaluation of Synthetic Fuel Character Effects on Rich-Lean Stationary Gas Turbine Combustion Systems

AP-2822 Final Report (RP1898-1), Vol. 1; $11.50

This report details the capabilities and limitations of rich-lean stationary gas turbine combustion systems, a class of combustor capable of low NO_x emission performance with fuels having high concentrations of nitrogen. This volume presents the results of subscale combustor hardware tests using synthetic fuels derived from coal and oil shale. The contractor is United Technologies Corp. *EPRI Project Manager: L. C. Angello*

Large Gas Turbine Modifications for Solar-Fossil Hybrid Operation

AP-2852 Final Report (RP1348-8); $16.00

Representative designs of gas turbines available today or possibly in the late 1980s were examined to determine the scope of modifications required for solar-fossil hybrid operation in a utility environment. The results indicate that modifying existing commercial gas turbines for this application is feasible and would be less costly than the development of new turbines. The contractor is United Technologies Research Center. *EPRI Project Manager: J. E. Bigger*

Ceramic Heat Exchanger Technology

AP-2883 Final Report (RP545-4); $13.00

This report describes a study to complement larger-scale heat exchanger development efforts by EPRI and DOE. Mechanical reliability calculations for a DOE-sponsored prototype heat exchanger module were made, and the fouling characteristics of ceramic heat exchangers when used with a coal-fired combustor were studied. Background information on the testing performed under DOE contract is included. The contractor is Solar Turbines, Inc. *EPRI Project Manager: W. T. Bakker*

Investigation and Research of Specific Combustion Turbine and Combined-Cycle Field Problems

AP-2888 Annual Report (RP1802); $14.50

This second annual report focuses on the problem of compressor wheel failure. It describes the examination of pieces of a burst wheel by metallographic and fractographic techniques, and presents the results of one-dimensional, two-dimensional, and refined fracture mechanics analyses. The contractor is Aptech Engineering Services, Inc. *EPRI Project Managers: R. L. Duncan and John Stringer*

Application Examples for Wind Turbine Siting Guidelines

AP-2906 Final Report (RP1520-1); $14.50

This report describes the trial application by two utilities of siting guidelines for wind turbine clusters. These examples are intended as an aid to other users of the guidelines. In addition, the sensitivity of wind turbine economics to two types of wind turbine performance models is examined. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: F. R. Goodman, Jr.*

Fundamental Studies in the Conversion of Coals to Fuels of Increased Hydrogen Content

AP-2912 Final Report (RP1655-1); $16.00

This report describes an experimental program examining two-stage coal conversion, in which a thermal dissolution step is followed by reaction in the presence of a catalyst. The study investigated the effects of solvent quality, the reaction sequence, and the reaction conditions in the two stages. It also addressed the roles of the catalyst and the solvent, the interrelationship between thermal and catalytic reactions, and the mechanism of coal dissolution. The contractor is Mobil Research and Development Corp. *EPRI Project Manager: L. F. Atherton*

Protective Coatings for Utility Gas Turbines

AP-2929 Final Report (RP1344-1); $13.00

Two optimized state-of-the-art protective coatings (one composed of cobalt, chromium, aluminum, and yttrium and one with those elements plus nickel) were selected and applied to first-stage vanes for testing in a utility gas turbine. (The best coating currently in use was also applied to enable performance comparisons.) In addition, laboratory and burner rig studies were conducted to identify promising coating systems for possible future development. The contractor is United Technologies Corp. *EPRI Project Manager: John Stringer*

Reliability and Availability Analyses of Coal-Fired Units: Validation of a Predictive Methodology

AP-2938 Final Report (RP1461-1); $17.50

This report describes the application of a reliability, availability, and maintainability prediction methodology and computer code (UNIRAM) to operating and hypothetical coal-fired units. These analyses were undertaken to validate and evaluate the methodology. The report also discusses how such unit-level analyses can complement existing utility procedures. The contractor is Arinc Research Corp. *EPRI Project Manager: Jerome Weiss*

COAL COMBUSTION SYSTEMS

Dry SO_2-Particulate Removal for Coal-Fired Boilers

CS-2894 Final Report (RP1682-2); Vol. 1; $13.00

A full-scale demonstration of dry sorbent injection for SO_2 removal was conducted on a 22-MW coal-fired boiler retrofitted with a fabric filter. The sorbent used was pulverized nahcolite, which was injected into the flue gas stream ahead of the fabric filter and downstream of the air preheater. This volume describes the demonstration and presents the results. It also discusses the technique's operability, the level of SO_2 removal attainable, and the impact of nahcolite injection on fabric filter operation. The contractor is KVB, Inc., for Public Service Co. of Colorado. *EPRI Project Manager: Richard Hooper*

Proceedings: Symposium on Flue Gas Desulfurization

CS-2897 Proceedings (TC82-926); Vol. 1, $32.50; Vol. 2, $32.50

This two-volume report contains the proceedings of an EPRI–EPA symposium on flue gas desulfurization held in May 1982 in Hollywood, Florida. Among various topics covered are dual-alkali, limestone/organic acid, lime/limestone, and dry systems; construction materials; reliability and maintenance; combined SO_x-NO_x removal; and by-product disposal and utilization. The contractor is Research Triangle Institute, Inc. *EPRI Project Manager: S. M. Dalton*

Evaluation of Peat as a Utility Boiler Fuel
CS-2913 Final Report (RP1838-1); $23.50

This report documents a study to assess the technical and economic feasibility of the direct combustion of peat for electric power generation in the United States. The study entailed a review of literature; the selection of a U.S. region for a hypothetical peat-harvesting operation; and an assessment of current practices for peat utilization in Europe, including peat harvesting, environmental control, and combustion technology. The contractor is Burns and Roe, Inc. *EPRI Project Manager: R. K. Manfred*

Operating and Maintenance Costs Survey of FGD Systems
CS-2915 Final Report (RP1872-2); $14.50

Data on the operating and maintenance costs of lime/limestone flue gas desulfurization systems in the United States were collected and correlated with key variables. This report presents the results and discusses the feasibility of predicting future maintenance costs from the existing cost data. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: T. M. Morasky*

Incipient Failure Detection for Fossil Power Plant Components
CS-2920 Proceedings (WS81-258); $46.00

This report contains the proceedings of an EPRI conference and workshop on techniques of incipient failure detection as applied to fossil fuel power plant components. The conference was held in August 1982 in Hartford, Connecticut. Among the topics covered are current utility practices, vibration signature analysis, acoustic methods, and available monitoring systems. The contractor is Science Applications, Inc. *EPRI Project Manager: A. F. Armor*

VERA2D: Program for 2-D Analysis of Flow, Heat, and Mass Transfer in Evaporative Cooling Towers
CS-2923 Final Report (RP1262-1); Vol. 1, $13.00; Vol. 2, $13.00

This report presents VERA2D, a computer program designed for the two-dimensional analysis of flow, heat, and mass transfer in wet cooling towers. The code is applicable to mechanical- and natural-draft cooling towers of both crossflow and counterflow design. Volume 1 describes the code's mathematical formulation, the solution procedure, and several applications. Volume 2 is a user's manual. The contractor is CHAM of North America, Inc. *EPRI Project Managers: H. E. Reilly and J. A. Bartz*

Comparative Economics of Indirect and Direct Dry/Wet Cooling-Tower Systems
CS-2925 Final Report (RP1260-21); $19.00

This report presents the results of studies to determine the comparative economics of indirect and direct dry/wet cooling-tower systems for 200- and 1000-MW coal-fired power plants at a semiarid western U.S. site. Comprehensive computer analyses were performed to optimize the design and to evaluate the performance and economics of the alternative systems for a range of fuel and water costs and makeup water requirements. The contractor is Robert D. Mitchell. *EPRI Project Manager: J. A. Bartz*

ELECTRICAL SYSTEMS

Human Factors Review of Electric Power Dispatch Control Centers
EL-1960 Final Report (RP1354-1); Vol. 5, $11.50; Vol. 6, $19.00

Volumes 5 and 6 of this six-volume report describe the factors influencing information management and presentation and discuss possible techniques for improving the presentation of information to system operators. The status of commercially available hardware and devices under development is reviewed. The contractor is Stagg Systems, Inc. *EPRI Project Manager: C. J. Frank*

Increasing Pipe Cable Section Lengths
EL-2847 Final Report (RP7847-1); $14.50

An experimental program was conducted to develop a reliable data base on modern pipe-type cable construction—a data base needed to enable maximizing of cable-pulling lengths (which offers cost savings). The main focus of the study was on determining a cable's performance under the three mechanical stress modes to which it is subjected during installation: tension and elongation, torsion, and sidewall (bearing) pressure in bends. The contractor is Power Technologies, Inc. *EPRI Project Manager: J. F. Shimshock*

Transverse-Field Vacuum Interrupter
EL-2890 Final Report (RP564-3); Vol. 1, $16.00; Vol. 2, $14.50

This report details Phase 3 of a project on the development of the transverse-field vacuum interrupter and its application as an ac fault current limiter and a dc circuit breaker. Volume 1 describes the successful field testing of this technology as a dc circuit breaker for 2500-A, 85-kV peak recovery voltage application. Volume 2 describes the continued development and application of this principle as an ac fault current limiter for 72.5/145-kV systems. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. W. Porter*

Longitudinal Unbalanced Loads on Transmission Line Structures
EL-2943-CCM Computer Code Manual (RP561-1); $17.50

This report describes two computer programs, BRODI2 and BROFLX, for calculating longitudinal unbalanced loads on transmission line structures. The theory relevant to the development of the codes is discussed, and a detailed description of input data and a series of sample problems are presented. The FORTRAN IV source listing is included for each program and its subroutines. The contractor is GAI Consultants, Inc. *EPRI Project Manager: P. L. Landers*

ENERGY ANALYSIS AND ENVIRONMENT

Sulfate Regional Experiment: Report of Findings
EA-1901 Final Report (RP862-1 and -2); Vol. 1, $28.00; Vol. 2, $20.50; Vol. 3, $29.50

This report analyzes the findings of the Sulfate Regional Experiment (SURE). Volume 1 describes how the data were obtained. Volume 2 presents an interpretive summary of the emission inventory and discusses field observations. Volume 3 analyzes sulfate variability, describes air quality modeling, and summarizes research achievements and limitations. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: G. R. Hilst*

Analysis of Power Plant Construction Lead Times
EA-2880 Final Report (RP1785-3), Vol. 1; $13.00

This volume details a study to develop information about power plant construction lead times (the period between the issuance of a construction permit and fuel loading). It discusses the underlying causes of long lead times and schedule delays and presents potential alternatives for controlling delays and reducing lead times. The contractor is Applied Decision Analysis, Inc. *EPRI Project Manager: S. W. Chapel*

Planning Studies for Measurement of Chemical Emissions in Stack Gases of Coal-Fired Power Plants
EA-2892 Final Report (RP1776-1); $20.50

As part of work to assess the potential adverse health effects of airborne chemical emissions from coal-fired power plants, a field survey plan for obtaining representative in-stack gas and particle samples was developed. The plan details which plants to sample, what sampling techniques to use, and what chemical analytic procedures and in vitro bioassays to apply. Plant design and operating parameters that can affect stack emissions are considered. The contractors are Southern Research Institute; Battelle, Columbus Laboratories; and Roth Associates, Inc. *EPRI Project Manager: Jacques Guertin*

Definitive Studies on Pole-Top Resuscitation
EA-2895 Final Report (TPS78-803); $10.00

This report examines the application of cardiopulmonary resuscitation (CPR) to an electric shock victim who is at the top of a utility pole. Questions on the use of CPR and other techniques at the pole top were investigated in experimental testing; the results clearly demonstrate the advantages of postponing CPR until the victim is lowered to the ground. Recommendations for emergency treatment at the scene are given. The contractor is Resuscitation Research Laboratory. *EPRI Project Manager: L. A. Sagan*

Issues in Implementing a Load Management Program for Direct Load Control
EA-2904 Final Report (RP2050-8); $11.50

This report describes the activities entailed in implementing load management, particularly direct load control programs. It presents a comprehensive chart that details the interrelationship of the various implementation activities and shows the different functional groups involved in the implementation process. The report also discusses key issues related to this process and describes five preliminary analytic approaches developed for dealing with those issues. The contractor is Energy Management Associates, Inc. *EPRI Project Managers: C. W. Gellings and Nancy Hassig*

Framework for Assessing EPRI Roles in Commercial Demonstration Projects
EA-2926 Final Report (RP1432-1 and -3); $11.50

This report describes an analytic framework and quantitative methodology for identifying the potential benefits of commercial demonstration projects and for assessing the value of alternative EPRI roles in these projects. The capabilities of the prototype methodology, which uses decision analysis techniques, are discussed. The contractors are Decision Focus, Inc., and Applied Decision Analysis, Inc. *EPRI Project Manager: S. W. Chapel*

ENERGY MANAGEMENT AND UTILIZATION

Analytic Predictions of Circulation and Vortices at Intakes
EM-2891 Final Report (RP1199-8); $11.50

This report describes a technique that uses mathematical modeling and near-field experimental data to predict vortex activity at intakes. A two-dimensional finite element flow model was used to predict circulation generation by Coriolis forces and by nonuniform bathymetry and flow toward the intake. Hydraulic experiments were conducted in several reservoir models at various withdrawal flow rates to generate near-field approach data. The contractor is the Alden Research Laboratory of the Worcester Polytechnic Institute. *EPRI Project Manager: Antonio Ferreira*

Utility Battery Operations and Applications
EM-2946-SR Special Report; $11.50

This report addresses utility battery operating requirements, value and design considerations, and siting considerations. It is intended (1) to provide battery developers with information that will allow them to optimize battery system designs for maximum benefit to utilities and their customers, and (2) to describe the array of options available to utility planners and operators regarding the use of battery energy storage and other storage schemes. *EPRI Project Manager: J. R. Birk*

Corrosion of Chromium-Coated Steel in Sodium Polysulfide Environments
EM-2947 Final Report (RP109-7); $13.00

Two types of chromium-rich coatings were applied to low-carbon steels and evaluated for corrosion resistance in sodium polysulfide environments typical of those in sodium-sulfur cells. Also, the effect of current flow through the coated steel was determined in special cells without a polysulfide environment. The contractor is Compagnie Générale d'Electricité. *EPRI Project Manager: B. C. Syrett*

NUCLEAR POWER

Core Design and Operating Data for Quad Cities-1, Cycle 3
NP-552 Interim Report (RP497-1); $11.50

This report presents the data needed to define the fuel and reactor operating characteristics for cycle 3 of Quad Cities-1. Design data cover fuel assemblies, core component arrangements, and core loading patterns. Hydraulic characteristics of the assemblies and the inlet orifices are also described. Operating data include core average exposure, thermal power, pressure, flux, inlet subcooling, control configuration, and axial in-core detector readings for each steady-state point. The contractor is General Electric Co. *EPRI Project Manager: B. A. Zolotar*

BWR Refill-Reflood Program: TRAC–BWR Component Development
NP-1583 Interim Report (RP1377-1); $10.00

This report describes the development of BWR component models that are necessary for the structuring of a best-estimate version of TRAC–BWR (transient reactor analysis code). Models were developed for the jet pumps, the steam separators, and the steam driers. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

PWR FLECHT SEASET System-Effects Natural Circulation and Reflux Condensation Task Plan
NP-2015 Interim Report (RP959-1); $32.00

The data requirements, instrumentation plan, facility, test matrix, and data reduction and analysis methods are described for the natural circulation cooling tasks of the FLECHT SEASET program. Appendixes provide information on the work scope, flow-resistance calculations, test parameter ranges, and upper plenum design aspects. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Avtar Singh*

SPEAR–BETA Fuel Performance Code System: Programmer's and User's Manuals
NP-2291-CCM Computer Code Manual (RP700-3, RP971-1 and -2), Vol. 2; $17.50

This report presents an overview of the BETA version of the SPEAR code system, which is a set of computer software (programs, subprograms, subroutines, functions, and data files) for computing the performance of nuclear fuel rods during in-reactor operations. The contractor is Entropy Limited. *EPRI Project Manager: S. T. Oldberg*

Hydrogen Mixing and Distribution in Containment Atmospheres
NP-2669 Final Report (RP1932-8); $23.50

Hydrogen mixing and distribution tests are reported for a modeled hydrogen release from a postulated small pipe break or from a pressurizer relief tank rupture disk into the simulated lower compartment of an LWR ice condenser plant. The tests, which in most cases used helium as a simulant for hydrogen, showed the gas in the lower compartment to be well mixed for both hydrogen release scenarios. The contractor is Westinghouse Hanford Co. *EPRI Project Manager: Loren Thompson*

ABAQUS–EPGEN: A General-Purpose Finite Element Code
NP-2709-CCM Computer Code Manual (RP964-5, RP1550-1), Vol. 3; $44.50

This volume is the example problems manual for the ABAQUE–EPGEN code. Detailed problems illustrate and verify significant aspects of the program's capability; most of these problems provide verification and include modeling and analysis techniques. The appendix documents a large set of basic verification cases that provide a fundamental check of the elements in the code. The contractor is Hibbitt, Karlsson and Sorensen. *EPRI Project Manager: H. T. Tang*

Full-Scale Turbine Missile Concrete Impact Experiments
NP-2745 Final Report (RP399-1); $16.00

This report describes four full-scale rocket-sled experiments conducted to provide data on the response of reinforced-concrete containment walls to impact and penetration by turbine missiles. Missile mass, velocity, and attitude were varied in the tests, as was the thickness of the wall's steel liner. Measures of damage included penetration depth, crater volume, and rear face cracking. Test results are compared with empirical penetration formulas. The contractor is Sandia National Laboratories. *EPRI Project Manager: G. E. Sliter*

Scale Modeling of Turbine Missile Impact Into Concrete
NP-2746 Final Report (RP393-1); $16.00

Scale-model turbine missile impact tests were conducted as part of a program to provide data on the impact resistance of structures that protect safety-related equipment in nuclear power plants. The experiments ($^1/_{11}$ scale) are described, and the results are compared with those from two full-scale tests. The contractor is SRI International. *EPRI Project Manager: G. E. Sliter*

Scale-Model Tests of Turbine Missile Containment by Reinforced Concrete
NP-2747 Final Report (RP399-2); $19.00

This report discusses 25 impact tests performed on $^1/_{11}$-scale models to determine the threshold velocity at which postulated turbine missiles perforate reinforced-concrete walls. The ability of current design formulas to predict the velocity at which turbine missiles perforate concrete structures is also assessed. The contractor is SRI International. *EPRI Project Manager: G. E. Sliter*

Fire Tests in Ventilated Rooms: Detection of Cable Tray and Exposure Fires
NP-2751 Interim Report (RP1165-1); $13.00

This report documents work to assess the response of typical commercial smoke detectors (ionization and photoelectric types) to cable tray and exposure fires in ventilated rooms representative of utility environments. An example of detector spacing requirements based on the results of cable tray fire tests is included. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: Joseph Matte III*

SIMULATE–E: A Nodal Core Analysis Program for LWRs
NP-2792-CCM Computer Code Manual (RP710-1, RP1761-9); $31.00

This report contains the method descriptions and user's manual for SIMULATE–E. A description of the coding, several sample problems, one benchmark problem, and code installation instructions are provided. The contractors are Yankee Atomic Electric Co. and Science Applications, Inc. *EPRI Project Managers: W. J. Eich, J. A. Naser, and B. A. Zolotar*

Cleaning Steam Generators Off-Line (Soaking) With Chelants
NP-2815 Final Report (RPS149-1); $20.50

This report describes laboratory testing to determine the feasibility of using organic chelating agents in an off-line soak application mode to arrest denting corrosion in steam generators. Several unique laboratory techniques for determining chelant thermal stability, chelant reaction rates with magnetite, and chelant corrosivity toward carbon steel structural materials are discussed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. W. Welty, Jr.*

Two-Phase Flow Characteristics During Reflooding of a Hot Vertical Tube

NP-2820 Final Report (RP248-1); $10.00

This report discusses a constant-injection bottom-reflood experimental program to measure transient void fraction during reflooding of a hot vertical tube. It presents the void fraction measurements (made with a gamma densitometer) and data showing different void fraction profiles for the two flow regimes (inverted annular and annular) observed at the quench front. The contractor is the University of California at Santa Barbara. *EPRI Project Manager: Loren Thompson*

EPRI–B&W Cooperative Program on PWR Fuel Rod Performance

NP-2848 Final Report (RP711-1); $16.00

This report describes a study of the in-reactor deformation and mechanical property changes of Zircaloy cladding. Zircaloy-4 fuel cladding specimens with different properties were irradiated in fueled and nonfueled conditions for two and four cycles of irradiation, respectively, to investigate irradiation creep and growth. Detailed results and engineering data are presented. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: David Franklin*

Nuclear Plant Response to Grid Electrical Disturbances

NP-2849 Final Report (RP1573-1); $19.00

Grid electrical disturbances (GEDs) were examined in terms of their effects on nuclear power plants. This report presents background material on GED phenomena and plant response, a system frequency response model for estimating load-frequency relationships during transient conditions, and an analysis of two recent industry surveys. Recommended improvements in analyzing, predicting, and monitoring plant response to GEDs are included, along with a model plant analysis. The contractor is EDS Nuclear, Inc. *EPRI Project Manager: H. G. Shugars*

General and Localized Corrosion of Carbon and Low-Alloy Steels in Oxygenated High-Temperature Water

NP-2853 Final Report (RPT115-5); $11.50

Tests were conducted to study the stress corrosion cracking susceptibility of two carbon steels (SA106 Grade B and SA333 Grade 6) and a low-alloy pressure vessel steel (A508-C12) in high-purity water as a function of oxygen concentration and temperature. The fracture surfaces of the test specimens were examined by scanning electron microscopy to determine the mode of failure. The results show that the steels studied are susceptible to stress corrosion cracking in high-temperature oxygenated water under monotonically rising loads. The contractor is Ohio State University. *EPRI Project Managers: J. C. Danko, M. J. Fox, and R. L. Jones*

Proceedings: Thermal Reactor Benchmark Calculations, Techniques, Results, and Applications

NP-2855 Proceedings (RP975-1); $47.50

This report contains the proceedings of an EPRI symposium held in May 1982 at the Brookhaven National Laboratory to discuss thermal reactor benchmark calculations, techniques, results, and applications. This was the third in a series of workshops on problems associated with nuclear data use and confirmation of LWR analysis. Areas in which measurements have been productive are discussed, as well as areas in which additional improvements can be made. The contractor is Brookhaven National Laboratory. *EPRI Project Manager: Odelli Ozer*

NATBWR: A Steady-State Model for Natural Circulation in BWRs

NP-2856-CCM Computer Code Manual (RP1561-1); $16.00

This report describes the NATBWR steady-state BWR natural circulation model and compares model predictions with natural circulation data from five operating BWRs. The behavior of the BWR system at reduced coolant inventory is also analyzed. Information on model use and programming is included. The contractor is S. Levy, Inc. *EPRI Project Manager: P. G. Bailey*

Magnetic Flux Leakage for Measurement of Crevice Gap Clearance and Tube Support Plate Inspection

NP-2857 Final Report (RPS125-1); $10.00

This report describes the design, construction, and testing of a variable reluctance probe suitable for field use and capable of predicting the crevice gap clearance at eight discrete points around the circumference of a steam generator tube. Suggestions for refining the probe are included. The contractor is Colorado State University. *EPRI Project Manager: S. T. Oldberg*

Eddy-Current NDE for Intergranular Attack

NP-2862 Final Report (RPS201-1); $13.00

This project, one of a series to develop nondestructive examination methods, focused on improved eddy-current inspection methods for detecting and characterizing intergranular attack in steam generator tubing. The report reviews metallographic and eddy-current data on 30 tubes removed from three operating plants. The contractor is J. A. Jones Applied Research Co. *EPRI Project Manager: S. T. Oldberg*

Optical Probe for Steam Generator Tube Dent Measurement

NP-2863 Final Report (RPS181-1); $10.00

This report describes the development of an optical profilometer for measuring steam generator tube denting at the tube–support plate intersection. Prototype and field-hardened devices were constructed and tested. The contractor is Sigma Research, Inc. *EPRI Project Manager: S. T. Oldberg*

Monitoring System for Determining Air Inleakage and Oxygen Concentrations in the Secondary Cycle of PWR Plants

NP-2865 Final Report (RPS187-1); $13.00

In order to obtain improved diagnostic information on corrosion and corrosion-related phenomena in PWR piping and system components, a system was developed for determining the concentration of dissolved gases in the condensate and feedwater process streams. The design, calibration, and laboratory testing of the prototype dissolved-gas analyzer are described and a series of measurements in an operating PWR is documented. The contractor is Radiological and Chemical Technology, Inc. *EPRI Project Manager: R. L. Coit*

Assessment of Chemical Processes for the Postaccident Decontamination of Reactor Coolant Systems

NP-2866 Final Report (RP2012-1); $22.00

This report evaluates previously used chemical decontamination processes and potentially useful new processes (14 in all). Both generic fuel damage accidents and the accident at TMI-2 are considered. Past usage, effectiveness, process limitations, safety considerations, and waste management are discussed. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: L. E. Anderson*

Personal Cooling in Nuclear Power Stations

NP-2868 Final Report (RP1705); $11.50

Two nonrestrictive cooling garments for nuclear plant workers exposed to high-temperature environments are evaluated: one that uses packets of frozen water and one that uses a circulating liquid. Laboratory simulation and field tests are described, and maximum exposure times for control and test subjects are reported. The contractor is Pennsylvania State University. *EPRI Project Manager: J. F. O'Brien*

Twenty-Six-Inch Pipe NDE Instrument Surveillance Test

NP-2869 Interim Report (RPT104-1); $13.00

A 26-in type-304 stainless steel pipe was exposed to high-purity oxygenated water and subjected to sustained axial stress in order to study the initiation and growth of intergranular stress corrosion cracking and to help develop nondestructive examination (NDE) techniques to detect and monitor such cracking. Tests to evaluate various NDE methods are reported. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Managers: J. D. Gilman and M. E. Lapides*

Thermal-Hydraulic Code Qualification: ATHOS2 and Data From Bugey-4 and Tricastin-1

NP-2872 Final Report (RPS154-2); $13.00

Data from steam generators at the Bugey-4 and Tricastin-1 nuclear power plants were used in the qualification of the ATHOS2 computer code, a three-dimensional, two-phase thermal-hydraulic code for the steady-state and transient analysis of recirculating-type steam generators. Code predictions of circulation ratio and temperature distribution across the tubesheet were compared with data for various cases. The contractor is Jaycor. *EPRI Project Manager: C. L. Williams*

Organization and Structure of an EPRI DATATRAN Data Bank

NP-2873 Interim Report (RP694-1); $10.00

This report describes the EPRI DATATRAN executive computer code and data base management system. It focuses on work to define a DATATRAN data base structure for the storage of experimental and plant transient data. The contractor is Intermountain Technologies, Inc. *EPRI Project Manager: P. G. Bailey*

Information System for Generation Availability: Executive Summary

NP-2875 Final Report (RP1391-10); $8.50

This report summarizes EPRI's research program (now concluded) on the requirements, applications, and design of an information system for generation availability (ISGA). The program's accomplishments are reviewed, and a guide to available material, most of which is in a form that enables direct application by individual utilities, is included. The contractor is TERA Corp. *EPRI Project Manager: Conway Chan*

Examination of Tube Samples From the Ginna Plant for Intergranular Attack
NP-2877 Interim Report (RP1618-2); $22.00

This report details the destructive examination of two tubes pulled from the Ginna nuclear power plant to characterize intergranular attack. The metallurgical and deposit chemistry data obtained from the samples are discussed, as well as the mechanisms of action of the suspect substances. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. D. Cubicciotti*

Plant Materials Program: Progress, June 1981 to May 1982
NP-2879-SR Special Report; $23.50

This is the second annual progress report of the plant materials subprogram, which was organized to address corrosion-related problems in LWRs. It includes an overview of plant materials problems with high impact on plant availability; a review of R&D work on these problems; and detailed discussions of progress in relevant technical topic areas, including intergranular stress corrosion cracking of austenitic steels and nickel-based alloys, environmentally assisted cracking of carbon and low-alloy steels, and improved fabrication technology. *EPRI Project Manager: J. T. A. Roberts*

Thermal and Hydraulic Code Verification: ATHOS2 and Model Boiler No. 2 Data
NP-2887 Final Report (RPS168-1); Vol. 1, $23.50; Vol. 2, $43.00; Vol. 3, $44.50

This report details steady-state and transient tests on the Westinghouse Model Boiler No. 2 steam generator and the use of test data to verify the ATHOS2 computer code. Volume 1 contains a project overview and describes the experimental work. Volumes 2 and 3 contain appendixes that document the data. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. L. Williams*

Windfield and Trajectory Models for Tornado-Propelled Objects
NP-2898 Final Report (RP308); $29.50

This report documents the third and final phase of analytic and experimental research to provide methods and test data for making realistic estimates of maximum tornado intensities and tornado missile trajectories. A method is proposed for using historical nationwide weather data to establish tornado intensity regions. A trajectory computer program and supporting rocket-sled test data are reported. The contractor is Gunther H. Redmann & Associates. *EPRI Project Manager: G. E. Sliter*

Low-Level-Radwaste Solidification
NP-2900 Topical Report (RP1557-1); $20.50

This report assesses state-of-the-art low-level-radwaste solidification processes and systems currently in use or under development. It discusses waste types, solidification agents, the general criteria affecting solidification technologies, and the chemistry and physics of the processes. Technical descriptions of 22 commercially available systems are presented, along with information on packaging efficiencies for specific wastes, shipping and burial containers, and container handling and storage systems. The contractor is Sargent & Lundy Engineers. *EPRI Project Manager: M. D. Naughton*

Manual Analog Call Confirmer Production Prototypes
NP-2901 Final Report (RPT101-6); $11.50

This report documents the design of production prototype models of the manual analog call confirmer (MACC), a portable electronic instrument to aid in the ultrasonic inspection of austenitic steel pipes subject to intergranular stress corrosion cracking. Electrical schematics are presented, and interface requirements and the theory of operation underlying the MACC design are discussed. The contractor is Zeger-Abrams, Inc. *EPRI Project Managers: M. E. Lapides and S. N. Liu*

Piping Seismic Test With Energy-Absorbing Devices
NP-2902 Final Report (RP1586-1); $17.50

The behavior of a complex spatial piping system under simulated seismic and thermal loadings was investigated. The control of seismic response by ductile steel energy-absorbing devices was compared with control by conventional mechanical shock arresters (snubbers). The test results indicate that ductile energy-absorbing restrainer systems have considerable promise. The contractor is the University of California at Berkeley. *EPRI Project Managers: Y. K. Tang and R. K. Winkleblack*

Comparison of COMETHE-III-J and FCODE-BETA Fission Gas Release Predictions With Measurements
NP-2903 Final Report (RP971-1); $10.00

This report describes an evaluation of the ability of two LWR fuel rod modeling codes, COMETHE-III-J and FCODE-BETA, to predict fission gas release from fuel. Code predictions were compared with measurements for 124 fuel rods from the EPRI fuel performance data base. The contractor is Science Applications, Inc. *EPRI Project Manager: David Franklin*

SPEAR-BETA Fuel Performance Code System: Fission Gas Release Module
NP-2905 Final Report (RP971-2); $10.00

This report presents a statistical fission gas release model that was added to the SPEAR-BETA computer code to enhance its capabilities. The structure, statistical patterns, and performance of the model are described, and a statistical data base comprising 139 fission gas release measurements is included. The contractor is Entropy Limited. *EPRI Project Manager: S. T. Oldberg*

Joint TMI-2 Information and Examination Program
NP-2907-SR Special Report; $13.00

This report describes EPRI's role in the TMI-2 information and examination program. It presents results to date from EPRI-funded projects on decontamination and dose reduction technology, fuel fission product transport and deposition, mechanical component survival, and primary-system pressure boundary characterization. Plans for future work are included. *EPRI Project Manager: J. T. A. Roberts*

Feasibility Study: New Cable Tray Hanger Concept for Nuclear Power Plants
NP-2910 Final Report (RP1937-1); $13.00

This report describes a feasibility study on the potential use of flexible connectors to reduce seismically induced loads in nuclear power plants. Finite element, classical analytic, and experimental examinations are detailed. Although it was concluded that a flexible connector system can provide a better dynamic response than conventional systems using rigid connectors, more work is required before this concept can be validated in actual plant designs. The contractors are Duke Power Co. and Clemson University. *EPRI Project Manager: Conway Chan*

Evaluation and Modification of COMETHE-III-J
NP-2911 Final Report (RP1452-1); $20.50

Predictions of the COMETHE-III-J fuel performance code were compared with experimental data. The report details modifications made to the code, evaluates the test results, and recommends further work. The contractor is The S. M. Stoller Corp. *EPRI Project Managers: F. Gelhaus and S. T. Oldberg*

SPEAR-BETA Fuel Performance Code System: Cost Implications Analysis Postprocessor
NP-2914 Final Report (RP971-2); $17.50

This report describes the application of the SPEAR-BETA postprocessor, COSTF, to an analysis of the fuel failure cost implications for cycle 8 of the Oyster Creek power plant. The analysis reports baseline costs, representing those actually incurred during cycle 8; the effects of varying 50 different cost parameters; and the effects of varying power levels and ramp rates. The contractor is Entropy Limited. *EPRI Project Manager: S. T. Oldberg*

Testing of a Natural Rubber Base Isolation System by an Explosively Simulated Earthquake
NP-2917 Final Report (RP810-7); $10.00

This report describes SIMQUAKE II scale-model tests to evaluate the performance of a base isolation system for protecting a reactor containment structure from strong ground motion. The base isolation system incorporates multilayer natural rubber bearings and a novel fail-safe support system. The contractor is the University of California at Berkeley. *EPRI Project Managers: Conway Chan, H. T. Tang, and Y. K Tang*

Base Isolation and Energy-Absorbing Restrainers for Seismic Protection of a Large Power Plant Component
NP-2918 Final Report (RP810-8); $11.50

This report examines how the interaction between large power plant components and the plant structure affects the components' seismic response. It assesses the feasibility of using (1) rubber bearing isolation as a retrofit strategy to improve component structural integrity, and (2) various energy-absorbing restrainers to connect a component to the primary structure. Four test model configurations are described, and the results of seismic shake table tests are presented. The contractor is the University of California at Berkeley. *EPRI Project Manager: Y. K. Tang*

Influence of Base Isolation on the Seismic Response of Light Secondary Equipment

NP-2919 Final Report (RP810-8); $10.00

This report presents shake table test results for three base isolation systems designed to reduce the amplification of seismic loads transmitted to light secondary systems and equipment. Recommendations for further research on a system combining the more successful base isolation principles are included. The contractor is the University of California at Berkeley. *EPRI Project Manager: Y. K. Tang*

Steam Generator Tube-Plugging and Tube-Sleeving Criteria

NP-2921 Final Report (RPS203-1); $20.50

This report presents a survey of current utility practices regarding steam generator tube plugging and tube sleeving. It also describes an analytic and experimental evaluation of mechanical strain as a parameter for use in tube-plugging and tube-sleeving criteria. The contractor is Failure Analysis Associates. *EPRI Project Manager: C. L. Williams*

Characterization of Contaminants in TMI-2 Systems

NP-2922 Interim Report (RP2012-3); $26.50

This report presents sample and measurement data used to characterize the contamination of the TMI-2 reactor coolant system and connected systems. It also describes materials of construction, physical location, operational history, and decontamination efforts for individual components. The contractor is Science Applications, Inc. *EPRI Project Managers: M. D. Naughton and R. K. Winkleblack*

Thermal Mixing in a Rectangular Geometry Model of a Cold Leg With High-Pressure Injection and a Downcomer

NP-2924 Interim Report (RP2122-4); $20.50

This report describes a series of tests to investigate fluid and thermal mixing in a transparent model of a PWR cold leg with high-pressure injection and a downcomer. Test conditions approximated the mixing phenomena in a prototypical reactor geometry. The results include both transient temperature data and movies of the cold leg mixing phenomena. The contractor is Science Applications, Inc. *EPRI Project Manager: J. P. Sursock*

Thermal Mixing in a Model Cold Leg and Downcomer at Low Flow Rates

NP-2935 Interim Report (RP2122-3); $35.50

This report describes fluid mixing experiments performed in a ⅕-scale facility to evaluate the effects of low flow rate and the thermal shield on fluid and thermal mixing phenomena in the cold leg and downcomer of certain PWRs. The test program simulated steady-state conditions thought to be extreme for small-break loss-of-coolant accidents. An analysis of transient and steady-state temperature records documented the mixing of the cold high-pressure-injection coolant water and the hot primary coolant water. The contractor is Creare, Inc. *EPRI Project Manager: K. H. Sun*

High-Temperature Filtration Measurements at the Isar BWR Plant

NP-2936 Final Report (RP1445-3); Vol. 1, $8.50; Vol. 2, $37.00

This report documents a program to assess the performance of an electromagnetic filter at the Isar nuclear power station in the Federal Republic of Germany. The filter is designed to process high-temperature drains. Volume 1 is a summary that describes the filter, the test program, and the findings. Volume 2 provides the complete test program description and data. The contractor is Kraftwerk Union Ag. *EPRI Project Manager: M. D. Naughton*

Assessment of SPEAR–FCODE–BETA for Fuel Licensing

NP-2939 Final Report (RP2061-4, -5, and -6); $10.00

This report assesses the adequacy of the SPEAR–FCODE–BETA code for simulating fuel performance for fuel licensing proceedings. It presents a detailed review of the thermal and mechanical performance models most important for fuel licensing—including fission gas release, fuel temperature, and cladding uniform strain. Modeling and usability improvements are recommended. The contractors are Battelle, Pacific Northwest Laboratories and Combustion Engineering, Inc. *EPRI Project Manager: D. G. Franklin*

Licensing Applications and Requirements of an Ideal Steady-State Fuel Performance Code

NP-2940 Final Report (RP2061-6); $8.50

This report identifies and characterizes the licensing applications and requirements for an ideal steady-state fuel performance code. Fifteen licensing applications are examined. Code input data needs and output requirements for each application are discussed, as well as necessary models to represent the pertinent fuel behavior phenomena. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: D. G. Franklin*

SPEAR–FCODE–GAMMA Functional Specifications

NP-2941 Final Report (RP2061-6); $8.50

This report documents SPEAR–FCODE–GAMMA, a conceptual fuel performance code for use in licensing analyses. The code's potential licensing-related applications are identified. General code specifications are discussed, as well as input and output data requirements, formatting aspects, and accuracy guidelines. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: D. G. Franklin*

Elastic Stress Analysis of Small-Radius U-Bend Steam Generator Tubes

NP-2944 Final Report (RPS194-4); $11.50

The effects of local geometry variations (produced during manufacture) on elastic stresses of small-radius U-bend tubes under simulated normal operating temperature and pressure were examined in detailed finite element analyses. Idealized geometry models and an actual, as-manufactured tube were analyzed. Specific geometrical factors and loading conditions affecting stresses were identified, and the stress results were compared with the locations of actual cracking in sample tubes. The contractor is Robert L. Cloud Associates, Inc. *EPRI Project Manager: C. L. Williams*

Modeling of Natural Circulation Phenomena in Nuclear Reactor Cooling Loops

NP-2951 Final Report (RP1731-2); $14.50

This report discusses the development of a steady-state and transient computer code to analyze single-phase natural circulation in multiple-loop PWRs with either U-tube or once-through steam generators. Code predictions are compared with experimental data, and the results of sensitivity studies of the major parameters involved are presented. The contractor is Technion–Israel Institute of Technology. *EPRI Project Manager: J. P. Sursock*

Fatigue Performance of Ni-Cr-Fe Alloy 600 Under Typical PWR Steam Generator Conditions

NP-2957 Final Report (RPS110-1); $31.00

This report describes an investigation of the fatigue performance of Alloy 600 tubing in various high-temperature environments representative of reference and faulted PWR steam generator conditions. The work included strain-controlled, low-cycle fatigue tests; load-controlled, high-cycle fatigue tests; and resonant ultrasonic fatigue tests. The test environments are described, and the results are presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: D. A. Steininger*

Study of Dilute Reagent Decontamination for Application in BWRs

NP-2960 Interim Report (RP828-1); $17.50

This report documents an experimental program to study the application of the dilute chemical decontamination method to BWR coolant systems. Several decontamination parameters were investigated in a once-through test facility, including reagent composition, temperature, concentration, pH, and oxidation-reduction characteristics. The results are discussed in terms of engineering considerations and are related to results from other laboratories. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: R. A. Shaw*

Residual Heat Removal Experience Review and Safety Analysis: PWRs

NSAC-52; $20.50

This report reviews events that have occurred during cold shutdown with the residual heat removal system (RHRS) operating to remove decay heat and events during the late stages of normal plant cooldown when the RHRS is placed in service. Safety implications are discussed. *EPRI Project Manager: Gary Vine*

Workshop on Emergency Response Facilities

NSAC-57 Proceedings; $25.00

This report contains the proceedings of an EPRI workshop held in September 1982 in Palo Alto, California, to review emergency response facility information systems. The workshop covered safety parameter display system design, software development, human factors engineering, and system integration. Associated NRC requirements and current utility experience are discussed. The contractor is Nuclear Software Services, Inc. *EPRI Project Manager: D. G. Cain*

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